

*DM Eagle*

# BULLETIN

*of the*

## American Association of Petroleum Geologists

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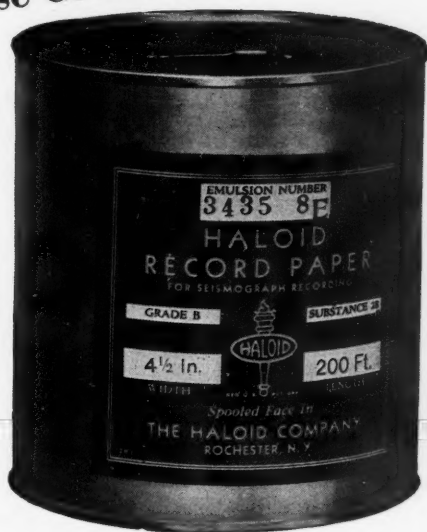
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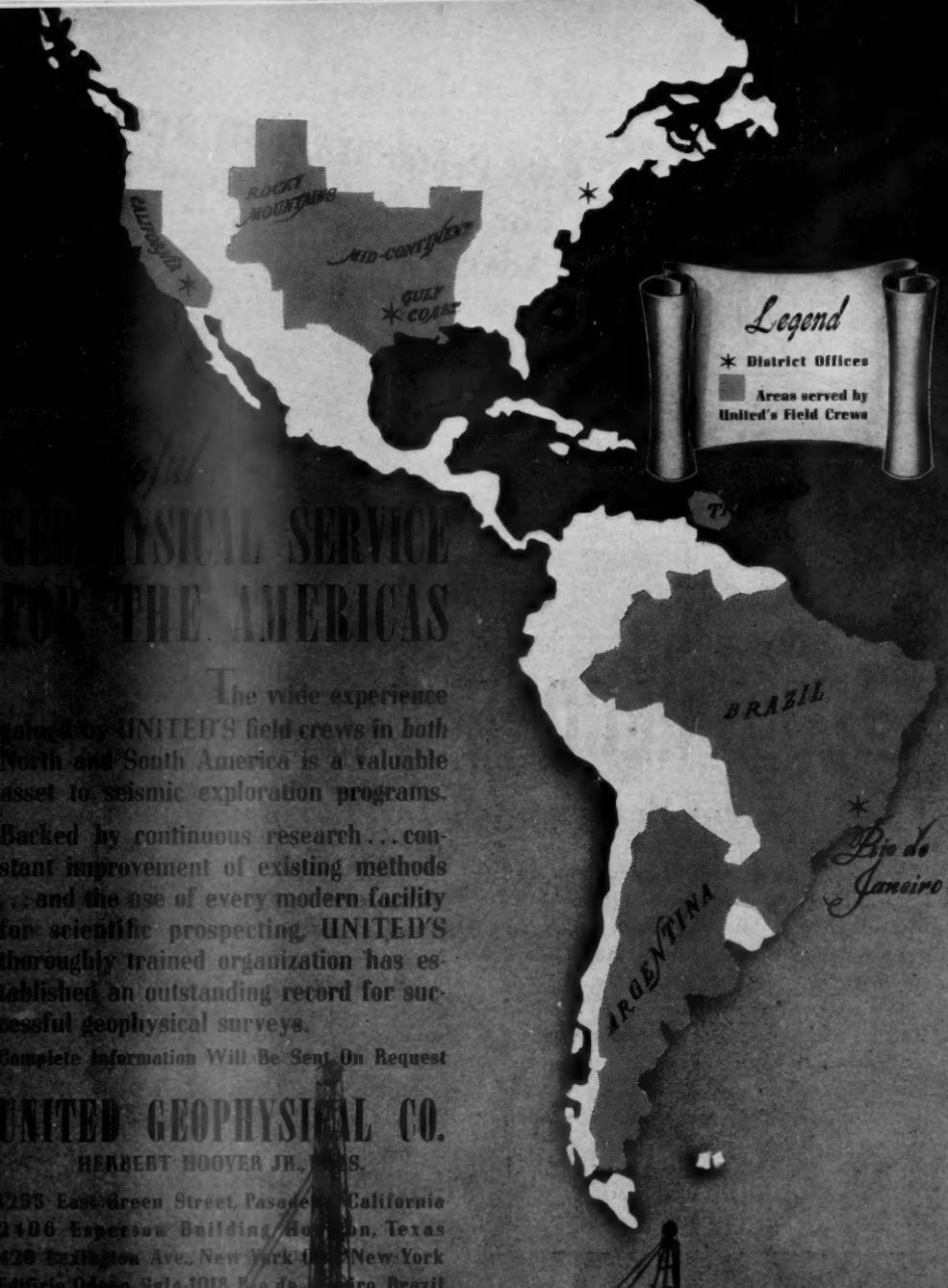
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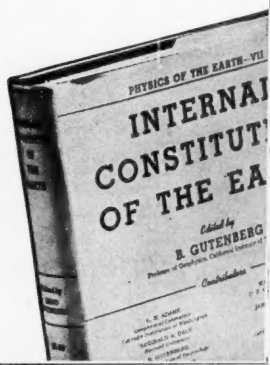
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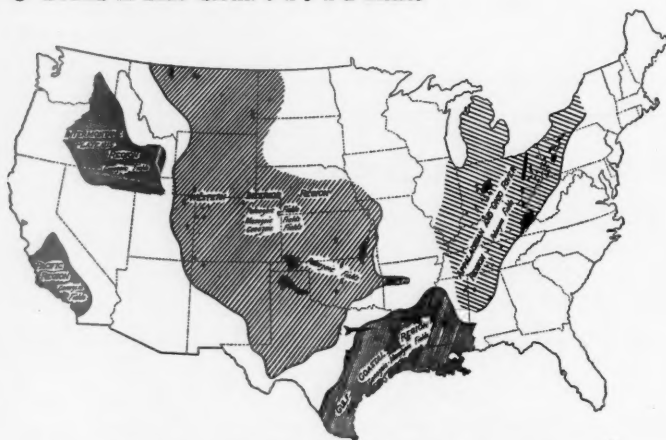
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*of the*  
AMERICAN ASSOCIATION OF  
PETROLEUM GEOLOGISTS

SEPTEMBER, 1940

RADIOACTIVITY OF SEDIMENTARY ROCKS AND  
ASSOCIATED PETROLEUM<sup>1</sup>

K. G. BELL,<sup>2</sup> CLARK GOODMAN,<sup>3</sup> AND W. L. WHITEHEAD<sup>3</sup>  
Cambridge, Massachusetts

ABSTRACT

Determinations of the radioactivity of 21 sedimentary rocks and 7 associated crude oils have been made by the precision method developed by R. D. Evans. The specimens consisted of cuttings and cores from wells in the Bartlesville, Cromwell, Frio, Woodbine, and Viola-Simpson formations. Considerable variability in radioactivity was found in the sandstones ( $1.4$  to  $0.19 \times 10^{-12}$  gms. Ra/gm.) and limestones ( $1.3$  to  $0.18 \times 10^{-12}$  gms. Ra/gm.). The radium content of limestones decreases with increasing purity. The shales were uniform ( $1.2$  to  $1.0 \times 10^{-12}$  gms. Ra/gm.). Apparently, discrete mineral particles in sandstone and impurities in limestone account for their occasional high radioactivity. The radon content of the crude oils ( $0.47$  to  $0.05 \times 10^{-12}$  curies/gm. of oil) was in one sample 38 times, and averaged 10 times, the amount in equilibrium with the radium present. The results corroborate the inferences of former investigators that radon tends to concentrate in crude oils. Maximum radon content and maximum ratio of radon to radium were found in petroleum produced from a permeable, Oligocene (Frio) sandstone of high radioactivity. Cracking of hydrocarbons with generation of hydrogen has been proved by S. C. Lind to result from bombardment with alpha rays. The amounts of radioactivity found in these crude oils are quantitatively sufficient to cause appreciable cracking by alpha radiation during geologic time. These reactions, together with subsequent hydrogenation, may account for important changes in petroleum. This hypothesis would also explain the presence of hydrogen in some natural gases. The hydrogen content of soil gases is suggested as a possible method of geochemical prospecting for oil fields.

INTRODUCTION

In recent years the great interest in the radioactivity of the materials of the earth's crust has been expressed chiefly by research on the radioactive properties of igneous and volcanic rocks. Some determinations of the radioactivity of sediments have been made; but,

<sup>1</sup> Presented in abstract before the joint session of the Society of Economic Geologists and the Geological Society of America, Minneapolis meeting, December 29, 1939. Manuscript received, April 5, 1940.

<sup>2</sup> Present address: United States Gypsum Company, 300 West Adams Street, Chicago, Illinois. Analytical work by Mr. Bell was done under the cooperative direction of Dr. Goodman of the radioactivity laboratory of the department of physics and Dr. Whitehead, of the department of geology, Massachusetts Institute of Technology.

<sup>3</sup> Massachusetts Institute of Technology.

except in the latest work on unconsolidated materials done by methods of the highest accuracy, little reliable information has been available on the activity of the various types of sedimentary rocks.

It has long been known that crude petroleum contains radioactive elements, of which the most important is the gas radon or radium emanation. As the crude oils contain little radium, the locus of the radium from which the emanation was derived has been conjectural.

The present research was undertaken to determine the radioactivity both of sedimentary rocks, sampled by cuttings and cores from oil wells, and of the crude petroleum produced from some of these wells. The sediments selected were sandstones and limestones in the pore spaces of which in most cases petroleum was contained. In certain wells the shales, superincumbent on these reservoir rocks, were also sampled. Altogether determinations of radioactivity were made on 21 sedimentary rocks and on 7 crude oils.

The object of the investigation was to fix, if possible, the source of the radium emanation in the crude oils, to correlate the physical properties of the oil and its radioactivity, and to determine the radioactivity of some sedimentary rocks, by using the precise analytical methods developed by Evans (1).<sup>4</sup>

The small number of samples precludes the work from being considered more than a preliminary study, but the results appear to warrant certain tentative conclusions and to justify continuation of the research.

#### GENERAL DISCUSSION

Practically all terrestrial materials contain measurable quantities of the radioactive elements. In the case of sedimentary deposits, these elements are laid down as components of some mineral in the beds or are precipitated with the sediment subject to the existing physical, colloidal, and chemical conditions. Not only are the atoms of these elements susceptible to subsequent changes of chemical affiliation, but they spontaneously disintegrate according to the laws of radioactivity.

Because of the relatively rapid decay of all the daughter elements, detectable quantities of the radioactive elements occur only in those sedimentary rocks in which one of the parent elements, uranium or thorium, was originally precipitated, with the exception of post-Pliocene formations. The same geologically short time also suffices to establish complete equilibrium between these parent elements and all of their decay products. Once this equilibrium has been attained,

<sup>4</sup> Numbers refer to references listed at the end of the paper. The writers wish to express their appreciation to Professor R. D. Evans for placing his apparatus at their disposal. Acknowledgment is also due Professor R. R. Shrock for generous aid.

it is possible to ascertain the concentration of the entire series by measuring any one member. Because of its convenient half period ( $T = 3.82$  days), chemical inertness and gaseous nature, radon is the member of the uranium-radium series usually measured. Thoron, the emanation of thorium, is isotopic with radon, but requires a flow method to measure because of its short decay period of 54.5 seconds. The present paper deals only with the radon and radium content of sedimentary rocks and associated crude oils. Thorium measurements on a number of the former samples are now in progress and will be reported later.

Research on the radioactivity of sedimentary rocks before 1921 has been summarized by Rogers (2).

Type of Rock	Locality	Num- ber of Speci- mens	Mean Ra- dium in $10^{-12}$ Gms./Gm. Rock	Observer
Sandstones, composite sample	Various	39	1.5	Joly (3)
Sandstones	Various	24	1.5	Fletcher (4)
Sandstones, slates, chalk, <i>et cetera</i>	Various	17	1.1	Strutt (5)
Sandstones, sandy shales	Limbury	8	1.7	Buchner (6)
Slates, shales, composite sample	Various	20	1.5	Joly (3)
Limestones, marbles	Europe	10	1.4	Buchner (6)
Limestones, dolomite, chalk	Various	24	0.8	Fletcher (4)

Bohn (7) gives figures for determinations by means of gold-leaf electroscopes upon two samples of soil from southern California. Schlundt (8) found the average radium content of travertine deposits, formed by springs now active at Mammoth Hot Springs, Yellowstone National Park, to be  $14.4 \times 10^{-12}$  gms./gm., a value which he states is about seven times that of ordinary limestones and sedimentary rocks. This work was done by means of an electroscope.

Piggot (9) in discussing the radium content of ocean-bottom sediments gives the results of his determinations and cites those of Joly and Pettersson upon the same type of material. Joly (10) obtained a general average of  $17.8 \times 10^{-12}$  gms./gm. for twelve samples of sediment collected by the *Challenger* and *Albatross*. Pettersson (11) obtained an average of  $10.96 \times 10^{-12}$  gms./gm. for twenty-eight samples of the same type of material. Piggot's average is  $6.52 \times 10^{-12}$  gms./gm. for twenty-eight samples. He calls attention to the extraordinarily high concentration of radium in these sediments compared to that in ordinary rocks. In recent work on six samples of argillaceous limestone from one ocean-bottom core, however, Piggot and Urry (12) obtain an average of  $1.48 \times 10^{-12}$  gms./Ra/gm.

Evans and Raitt (13) give the following results of radium determinations made in connection with cosmic-ray studies.

<i>Description of Rock</i>	<i>Radium in <math>10^{-12}</math> Gms./Gm.</i>
Limestone. Cormorant Lake, Manitoba	0.11
Limestone. Riverside, California	0.32
Kaibab Limestone. North Rim, Grand Canyon	0.95
Quartzite. Crucero Alto, Peru	0.20
Limestone. Quarry in Minneapolis, Minn.	0.60
Quartzose sandstone. Zion Canyon, Utah	0.32

Evans and Kip (14) report an average radium content of  $2.5 \times 10^{-12}$  gms./gm. in ocean-bottom sediments without regard to the type of deposit. They also report the following radium concentrations in East Indian Mesozoic clays believed to be of abyssal origin.

<i>Type of Sediment</i>	<i>Radium in <math>10^{-12}</math> Gms./Gm.</i>
Abyssal clay	$3.56 \pm 0.03$
Manganese nodule	$1.63 \pm 0.04$
Radiolarite, red	$0.09 \pm 0.01$
Radiolarite, creamy pink	$0.28 \pm 0.07$
Marl	$0.06 \pm 0.02$
Radiolarite	$0.31 \pm 0.01$

The earliest investigator to mention the radioactivity of crude oils appears to have been Burton (15) who made experiments in 1904 on crude oil from Petrolia, Ontario. His conclusions were the following. 1. Fresh crude petroleum contains a strongly radioactive gas which is similar in its rate of decay, and also in the rate of decay of the induced radioactivity which it produces, to the emanation from radium. 2. There are indications of the existence in crude petroleum of slight traces of a radioactive substance more persistent than the radium emanation. 3. The amount of emanation present appears to be considerably more than is required for equilibrium with the slight traces of the more persistent radioactive material contained in the petroleum, indicating that crude oil has the property of absorbing radon in fairly high concentrations.

Von Trautenberg (16) has established that Henry's Law applies to the absorption of emanation in liquids. Boyle (17) states that petroleum products absorb forty to fifty times the amount of radium emanation and five times the amount of thorium emanation that water will absorb. The following liquids are listed in the order of increasing solubilities of radon: distilled water, sulphuric acid, ethyl alcohol, petroleum. The presence of dissolved salt in the water tends to lessen slightly the absorption. These data indicate that radium emanation will be dissolved in crude oils in greater quantity than in ground waters.

Using an electroscope, Bohn (7) found that samples of crude oil from two wells in the Montebello oil field of California had an average

emanation content of  $2.0 \times 10^{-12}$  curies per liter which is of the same order of magnitude as the emanation found in deep well water from the same region. Results for samples from the two wells are, well Temple No. 9 =  $1.9 \times 10^{-12}$  curies per liter and well Temple No. 15 =  $2.2 \times 10^{-12}$  curies per liter. These values must be considered to be slightly low, as unsatisfactory methods of collecting samples allowed some of the emanation to escape. Samples of oil were stored for one month and then tested for radium with negative results. This observation supported the conclusion previously reached by Engler (18) that the radioactivity of crude oils is mainly due to emanation and not to the presence of radium salts in solution.

Hahn and Born (19) describe a rather frequent occurrence of helium in the North German salt domes which they believe originates from the alpha radiation of polonium. These investigators offer the hypothesis that if the lead isotope, radium D, were concentrated together with the potassium chlorides, the equilibrium quantity of polonium would soon be re-established. Samples of waters from oil wells near salt domes were tested for radioactivity, and quantities of radium were found which are higher than the most radioactive springs in Germany. Attention also is called to the high radioactivity of oil-well waters in Russia. The Russian scientists proposed that the absorption of radium emanation by the oil itself has affected the water without claiming a relation to salt domes.

Nikitin and Komleff (20) find that quantitative tests upon waters from oil-bearing rocks show that radium emanation is present in higher concentrations than in waters from other regions. The quantity of emanation from neighboring wells which tap the same formations are observed to differ widely.

Aeckerlein (21) describes measurements of radium emanation in wells and of radium content in well cuttings and states that the emanation content appears higher than would be expected from the radium content. Plotting the emanation content and the radium content separately as a function of the depth it is seen that the anomalies occur close together but with the maxima of the former at slightly lesser depths than the anomalies of the latter. This is explained by the tendency of the gas to rise to lesser depth, possibly in conjunction with an upward air current in the well.

Bogoiavlensky (22), in discussing the radiometric exploration of oil deposits, states that the penetrating gamma radiation changes sharply between places a few meters apart. Measurements continued over a period of 3 years showed no variation in intensity at the various points. The author concludes that the colloidal materials underlying

oil beds are richer in radium on account of the absorbing power of colloids although he offers no experimental evidence to support this conclusion.

Bobin (23) notes that the water from Well No. 1 in the Ukhta oil field (USSR) has an average content of radium by the emanation method of  $7.58 \times 10^{-12}$  and of thorium-X  $2.186 \times 10^{-12}$  grams per liter. Repeated analyses of samples stored 28–30 days showed that when water leaves the well it contains only 9 per cent of the radiothorium required for equilibrium with the thorium-X present. The mesothorium-1 content was not determined but assumed to be  $2.05 \times 10^{-12}$  grams per liter. Calculations show that about sixty hours elapse between the time when the water acquires its activity and the time it is brought to the surface. In comparison with other data these figures appear to be rather high but bring out the fact that the amount of parent radioactive elements may be considerably less than is required for equilibrium with their decay products, as was also found by Burton, Engler, and Bohn.

From a consideration of these researches two important points are evident. The first is that crude oils and the waters and brines associated with crude oils have a high degree of radioactivity as compared with that of ordinary ground waters found in regions remote from oil fields. In the case of crude oils, these facts have been explained by the high absorbing power of petroleum for radium emanation. The second point is that the quantity of radium present in crude oils is considerably less than that which is required for equilibrium with the emanation which is present when the oil comes from the ground. The property of crude oils to absorb emanation from the containing and adjacent sediments has been suggested as the cause of this relation. Because of the slow migration of petroleum during the lifetime of a given quantity of emanation, the latter might be inferred to remain in the immediate vicinity of the point where it is generated, rather than being dissipated by the normal circulation of ordinary ground waters.

Recent research indicates that some of the early determinations are entirely unreliable (24). Modern instruments of detection give much more accurate results than even the better measurements of the past obtained with electroscopes. Highest accuracy is still lacking in much of the present-day work because reliable radium standards in dilute concentrations are not generally available and calibration between various workers is seldom undertaken. The National Research Council Committee on Standards of Radioactivity is sponsoring an international intercalibration of radioactivity measurements (25) which should aid in correcting many of the past inaccuracies and place future measurements on a firmer scientific basis.

## METHODS OF DETERMINING RADIOACTIVITY

The radon and radium determinations involve (1) removal of the radon from the sample and (2) quantitative measurements of this radon through the ionization produced by its alpha rays. Except for the minor modifications indicated below, the techniques developed by Evans (1) have been used for all measurements.

The containers for the crude-oil samples consisted of 250 cc. Dreschel washing bottles fitted with hollow, ground-glass stoppers provided with two glass tubes, one of which extended to the bottom of the bottle thus permitting nitrogen to be bubbled through the sample, while the other tube provided an exit for the gases drawn off. The protruding ends of the glass tubes were drawn out to slender, sealed tips which were protected during shipment by caps of glass tubing attached with sealing wax. Each sample consisted of 100 cc. of crude oil, shipped to the laboratory via air mail immediately after being taken from the well.

The removal of radon was accomplished by slowly heating the oil to approximately 100°C. and bubbling radioactively inert nitrogen through the oil. Premature escape of the radon and introduction of laboratory air were prevented by attaching the exit tube to the reflux condenser with sealing wax. The system was then evacuated and the glass tip broken by means of a small cylinder of iron in the condenser. This was controlled externally by a solenoid. Because of the appreciable water content of the oils, it was necessary to have the gases flow through a phosphoric anhydride drying-tube on their way to the ionization chamber.

In order to determine the completeness of de-emanation, the procedure was repeated for some of the samples immediately after the ionization chamber was filled, the gas being collected in an evacuated bulb. Subsequent determination of the radon in the bulb was made, and the results indicate an average efficiency of 90 per cent for the initial de-emanation. The radon contents reported in Table II include this 10 per cent retention correction. In addition, the observed activity has been corrected for the decay of radon during transit. Hence, the reported radon concentrations accurately represent that contained in the oil as it flowed from the well.

The radium content of the oil was determined for some samples by one of the following two methods and for others by both methods. The radon content in equilibrium with the radium in the oil was measured after storage of the oil for 30 days, during which time essentially all of the initial radon would have decayed. The radium content of the residue obtained by burning the sample was measured by dissolving in nitric acid and analyzing in the usual manner for liquid samples.

Because of the high content of volatiles in the sediments, it was necessary to ignite the samples before they could be treated by the direct-fusion method. De-emanation accompanies ignition, and it is necessary to reestablish the equilibrium radon content by storage in sealed containers before the fusion treatment. This method is completely described by Evans (1).

TABLE I  
RADIUM CONTENT AND DESCRIPTION OF SEDIMENTARY ROCK SAMPLES

Sample Number*	Rock Type	Formation	Depth (in Feet)	Age	Radium in $10^{-12}$ Gms./Gm. of Rock†
<i>Well—A. McKinney No. 5, Sun field, Starr Co., Texas</i>					
1	Clay shale	—	5,096-7	Oligocene	$1.15 \pm .07$
2	Quartz sandstone	Frio	5,108-16	Oligocene	$1.42 \pm .10$
<i>Well—McKinney No. 6, Sun field, Starr Co., Texas</i>					
3	Clay shale	—	4,649-53	Oligocene	$1.09 \pm .06$
4	Quartz sandstone	Frio	4,657-8	Oligocene	$0.80 \pm .05$
<i>Well—Olivares No. 5, Sun field, Starr Co., Texas</i>					
5	Clay shale	—	4,636-7	Oligocene	$1.05 \pm .05$
6	Quartz sandstone	Frio	4,645-50	Oligocene	$1.17 \pm .06$
<i>Well—No. 1 Dalley, Navarro Crossing, Texas</i>					
7	Shale	—	5,851-67	Cretaceous	$1.09 \pm .15$
8	Quartz sandstone	Woodbine	5,889-94	Cretaceous	$0.19 \pm .05$
<i>Well—No. 1 C. C. Hill, Navarro Crossing, Texas</i>					
9	Shale	—	5,916-17	Cretaceous	$1.07 \pm .10$
10	Quartz sandstone	Woodbine	5,934-35	Cretaceous	$0.22 \pm .02$
<i>Well—Nowata Co., Oklahoma</i>					
11	Sandstone	Bartlesville	494	Pennsylvanian	$0.82 \pm .06$
12	Sandstone	Bartlesville	505	Pennsylvanian	$0.58 \pm .05$
13	Sandstone	Bartlesville	512	Pennsylvanian	$0.51 \pm .05$
<i>Well—Ector Co., Texas</i>					
14	Limestone	Permian limestone	4,096	Permian	$0.33 \pm .05$
<i>Well—Moore 1A Harper, Fills pool, Oklahoma</i>					
15	Shaly limestone	Viola	3,810-35	Ordovician	$0.78 \pm .06$
16	Shaly limestone, sandstone	McLish	4,245-81	Ordovician	$0.29 \pm .03$
17	Limestone	—	4,365-73	Ordovician	$0.18 \pm .03$
<i>Well—Moore No. 7 Schauers, Fills pool, Oklahoma</i>					
18	Shaly sandstone	Cromwell	2,510-40	Pennsylvanian	$0.67 \pm .05$
19	Shaly limestone	Viola	3,780-00	Ordovician	$1.30 \pm .07$
20	Limestone, shale, quartz	McLish	4,265-70	Ordovician	$0.31 \pm .03$
21	Dolomite	—	4,370-75	Ordovician	$0.29 \pm .03$

\* Numbers serve to identify samples in subsequent discussion.

† The estimated accuracy of each measurement is indicated by the usual probable error ( $0.67 \times$  standard deviation of the mean of hourly ionization measurements, including backgrounds and calibration).

As previously mentioned, one of the principal sources of error in previous radon and radium measurements has been the use of unreliable standard solutions. The apparatus used had previously been accurately standardized using the Lind-Evans standard radium solution (24).

## SOURCE OF SAMPLES

Sedimentary rocks on which determinations of radioactivity were made include six core samples of the Oligocene from three wells in the Sun field, Starr County, Texas; four core samples of the Cretaceous from two wells at Navarro Crossing, Texas; seven samples of cuttings of the Pennsylvanian and Ordovician from two wells in the Fitts pool, Oklahoma; one core sample of Permian limestone from Ector County, Texas; and three core samples of Bartlesville (Pennsylvanian) sandstone from a well in Nowata County, Oklahoma (Table I). Crude oil samples were obtained from the producing formations sampled in the Sun field, Fitts pool, and from Navarro Crossing.

The success of the research was dependent on the obtaining of accurately located rock samples and of carefully collected samples of crude oil and dissolved gas in the special containers and on prompt shipment by air mail of the latter. Active coöperation in the field by many individuals is gratefully recognized. Acknowledgment is specially due F. H. Lahee and C. R. Nichols of the Sun Oil Company; S. A. Thompson, John W. Clark and John E. Van Dall of the Magnolia Petroleum Company; and F. W. Rolshausen of the Humble Oil and Refining Company.

## RESULTS OF DETERMINATIONS

The observed radium content and complete data on samples of the sedimentary rocks are given in Table I.

The radioactivity measurements on several crude oils are presented, together with a description of their derivation, in Table II.

TABLE II  
RADIOACTIVITY MEASUREMENTS ON CRUDE OILS

<i>Oil Sample</i>	<i>Specific Gravity in Deg. A.P.I.</i>	<i>Radon in 10<sup>-12</sup> Curies/Gm. Oil</i>	<i>Radium in 10<sup>-12</sup> Gms./Gm. Oil</i>	<i>Radon:Radium Ratio</i>
a	45.5	0.344	0.009	38.2
b	45.5	0.466	0.031	15.0
c	37	0.101	0.024	4.2
d	37	0.049	0.007	7.0
e	37	0.136	0.034	4.0
f	37	0.143	0.005	28.6
g	35	0.087	0.019	4.6

<i>Company Well</i>	<i>Location</i>	<i>Producing Formation</i>	<i>Age</i>
a. Sun Oil Co., Olivares No. 5	Sun field, Starr Co., Texas	Frio	Oligocene
b. Sun Oil Co., McKinney No. 6	Sun field, Starr Co., Texas	Frio	Oligocene
c. Humble Oil Co., Dailey No. 1	Navarro Crossing, Texas	Woodbine	Cretaceous
d. Magnolia Petroleum Co., Moore 1B Harper	Fitts pool, Oklahoma	Cromwell	Pennsylvanian
e. Magnolia Petroleum Co., Moore No. 7A Schauers	Fitts pool, Oklahoma	Cromwell	Pennsylvanian
f. Magnolia Petroleum Co., Moore No. 1A Harper	Fitts pool, Oklahoma	Viola-Simpson	Ordovician
g. Magnolia Petroleum Co., Moore No. 7 Schauers	Fitts pool, Oklahoma	Viola-Simpson	Ordovician

The difference between radon expressed in curies per gram of oil and grams of radium per gram of oil represents the excess of radon over that in equilibrium with the radium contained in the oil. This excess may be expressed in curies per gram of oil or by the radon:radium ratio. The amount of radon above the quantity in equilibrium with the radium in the oil must represent radon derived from exterior sources.

## DISCUSSION OF RESULTS

## SEDIMENTARY ROCKS

The rocks studied in the present research, all Oligocene or older, are of sufficient age that radioactive equilibrium has been established

TABLE III  
COMPARISON OF RADIUM MEASUREMENTS ON BASIS OF ROCK TYPE

Sample	Type of Rock	Age	Radium in $10^{-12}$ Gms./Gm. Rock
1	Clay shale	Oligocene	$1.15 \pm .07$
3	Clay shale	Oligocene	$1.03 \pm .05$
5	Clay shale	Oligocene	$1.05 \pm .05$
7	Shale	Cretaceous	$1.09 \pm .15$
9	Shale	Cretaceous	$1.07 \pm .10$
2	Quartz sandstone	Oligocene	$1.42 \pm .10$
6	Quartz sandstone	Oligocene	$1.17 \pm .06$
4	Quartz sandstone	Oligocene	$0.80 \pm .04$
18	Shaly sandstone	Pennsylvanian	$0.67 \pm .05$
11	Sandstone	Pennsylvanian	$0.82 \pm .06$
12	Sandstone	Pennsylvanian	$0.58 \pm .05$
13	Sandstone	Pennsylvanian	$0.51 \pm .05$
10	Quartz sandstone	Cretaceous	$0.22 \pm .02$
8	Quartz sandstone	Cretaceous	$0.19 \pm .05$
14	Limestone	Permian	$0.33 \pm .05$
21	Dolomite	Ordovician	$0.29 \pm .03$
17	Limestone	Ordovician	$0.18 \pm .03$
19	Shaly limestone	Ordovician	$1.30 \pm .07$
15	Shaly limestone	Ordovician	$0.78 \pm .06$
16	Shaly limestone, sandstone	Ordovician	$0.29 \pm .03$
20	Shaly limestone, shale, limestone, quartz	Ordovician	$0.31 \pm .03$

with uranium. No detectable amount of original radium is still present and, as might be expected, no relation of radioactivity to the age of the sediment is observed. The various types of sediments appear to show definite characteristics of radioactivity, as is seen from the tabulation according to lithologic type given in Table III. Radioactivity is highly variable in sandstones, less so in limestones and is essentially uniform in shales. Maximum radioactivity of about the same order of magnitude occurs in all three classes of rocks. The average maximum is  $1.29 \times 10^{-12}$  grams of radium per gram of rock which is some-

what lower than values determined on similar material by earlier investigators. The minimum radioactivities of sandstones and limestones, about  $0.18 \times 10^{-12}$  grams of radium per gram of rock, agree well with the similar values of Evans and Raitt (13). Too few determinations have been made, however, to allow us to conclude that these characteristics are generally applicable. Further research is essential to ascertain the reality of the trends in radioactivity indicated by the present available data.

The sandstones upon which determinations were made vary between 1.42 and  $0.19 \times 10^{-12}$ , the average being  $0.71 \times 10^{-12}$  gm. Ra/gm. rock. The purest sandstone is the lowest in radioactivity and is comparable, in this respect, with the sandstone of Berea, Ohio ( $0.23 \times 10^{-12}$  gm. Ra/gm.) selected as one of the standard rock samples to be used in the international intercalibration of radioactivity (25). Quartzite of even lower radioactivity ( $0.07 \times 10^{-12}$  gm. Ra/gm.) has been found by Goodman, and pure quartz may contain even lower concentrations of the radioactive elements.

The locus of radioactivity in sandstones is to be sought in impurities, probably discrete mineral particles and shaly material. The highly radioactive muscovite and biotite separated by Piggot (26) from granites are significant in this connection. The heavy mineral content of soils was found by Clark and Botset (27) to be closely related to radon content, and heavy minerals may also be an important source of radioactivity in sandstones.

The pure limestones and dolomites studied are apparently as low in radioactivity as some pure sandstones. High radioactivity occurs in limestone with shale intercalations, but sandy limestones with thin quartz-bearing strata are low in radioactive material. The average for the seven limestones upon which determinations were made is  $0.50 \times 10^{-12}$  gms. Ra/gm. rock, which is the same as that of four limestones described by Evans and Raitt (13). Maximum radioactivity was found by these authors in the Kaibab limestone of the Grand Canyon ( $0.95 \times 10^{-12}$  gm. Ra/gm.) and by the present investigators in the shaly Ordovician limestone of the Fitts pool, Oklahoma ( $1.30 \times 10^{-12}$  gm. Ra/gm.). Impurities apparently account for unusually high radioactivity in some limestones, but it would seem that the average radioactivity of limestones is less than that of sandstones and that limestones in general are less variable in radioactivity than sandstones.

The average radioactivity of the few shales studied is  $1.08 \times 10^{-12}$  gm. Ra/gm. rock, a value which is somewhat less than the maximum of the other types of sedimentary rocks. Deviation from the mean in

the determinations on shales is no greater than the experimental error. The limited data indicate that shales are of fairly constant and of relatively high radioactivity.

Before the foregoing tentative conclusions can be accepted, many more determinations of the radioactivity of marine sedimentary rocks must be made. Proof of the hypothetical suggestions as to the locus of radioactivity in all of the types of marine sediments mentioned heretofore also is dependent on further investigations. Such additional research is planned on the samples already studied and on other sedimentary rocks.

It is desirable to increase the number of determinations of radioactivity, not only on marine sediments in order to confirm the trends now indicated, but also on fresh-water and land sediments. The influence of sea water on radioactivity may be apparent from comparison of such results. If uniform radioactivity in contemporaneous shales is real and is explicable by adsorption of uranium by colloidal constituents, then variation of radioactivity in shales of widely different ages may suggest variation of uranium in the sea during geologic time. As suggested by Evans and his associates (14, 28) further work should be done on the radioactive characteristics of abyssal marine deposits. No accurate determinations of radioactivity in organic sediments or varved glacial clays have been made. Comparison of such determinations on coal, black shale and ordinary shale would be of interest.

More detailed investigations are planned on the radioactivity of detrital minerals in sandstone. Variations in radioactivity of sandstones may show relations to shore lines and to areas of denudation of differing geological character. Such relations are suggested by the highly radioactive limestones from the Grand Canyon, from Minnesota and from southeastern Oklahoma. Determinations of the radioactivity of insoluble residues from limestones may corroborate these inferences. Radioactive constituents of shales and clays may be isolated by centrifuging. They may then be studied for effects of adsorption during deposition.

#### CRUDE OILS

As seen in Table II, the quantity of both radon and radium in the crude oils investigated is highly variable. Average radon content is  $0.19 \times 10^{-12}$  curies/gm. and average radium is  $0.018 \times 10^{-12}$  gm./gm. of oil. Maximum content of both elements is somewhat above twice the average and minimum content about one-quarter of the average value. The radon:radium ratio in all samples is over 4, averaging 10.5

which proves conclusively that most of the radon in the crude oils came from a source other than the radium in the oil.

Radon formed in the sedimentary rocks through which the petroleum passed on its way to the well has been dissolved in the oil. No direct relation between excess radon in the crude oil and the radium content of rock from which the crude oil was produced is evident from comparison of the data of Tables I and II or from the averages given in Table IV.

TABLE IV  
RADIOACTIVITY MEASUREMENTS OF SOME CRUDE OILS AND THEIR ASSOCIATED  
ROCK FORMATIONS

Rock		Oil			
Age	Formation	Ra in $10^{-12}$ Gm./Gm.	Rn in $10^{-12}$ Cu- ries/Gm.	Ra in $10^{-12}$ Gms./Gm.	Radon: Radium Ratio
Oligocene	Frio sandstone	0.985	0.405	0.020	20.3
Cretaceous	Woodbine sandstone	0.19	0.101	0.024	4.2
Pennsylvanian	Cromwell sandstone	0.67	0.093	0.020	4.7
Ordovician	Viola-Simpson limestone	1.04	0.138	0.018	7.7

Maximum radon content and maximum ratio of radon to radium are found in the oil from the Oligocene Frio sandstone, which is high in radium, permeable and capped by shale. Low radon and low excess radon are present in crude oils from the pure sandstone of the Cretaceous Woodbine formation and from the shaly Pennsylvanian sandstone of the Cromwell formation. The crude oil from the Viola-Simpson limestone is intermediate in content of radon and in excess radon although the rock is of relatively high radioactivity. Apparently much of the radon formed in the limestone is retained in the rock.

The lack of precise quantitative relation between the radioactivity of the producing rock and excess radon in the oil is not surprising. The crude oil samples, which were taken at about atmospheric pressure, contained little gas. At the pressure and temperature of the oil-field reservoir, however, volumes of gas fifty to several hundred times the volume of the crude oil are dissolved in or associated with the oil. To obtain the radon content of the reservoir fluid, the radon content of the natural gas produced with the crude oil and the gas-oil ratio of the well should be known. Determinations of radioactivity of the natural gases were beyond the scope of this preliminary research and remain for future investigation.

Some difference is to be expected between the radioactivity of rock at the well and the oil and gas from the well, on account of migration of the fluids to the well from some distance during the life of the con-

tained radon. Rock samples from the well may not have the same radioactivity as the rock through which the oil and gas flowed to the well. Investigations of a greater number of rock and fluid samples from various wells in a given sedimentary formation might improve this correlation.

The accessibility to the reservoir fluids of radon formed in the containing rocks is also doubtless variable with grain size, porosity, and permeability of the sediment. Radon produced in the more pervious strata through which crude oil and gas flow is available for solution in the fluids, while radon originating in fine-grained layers of low permeability such as silty or shaly intercalations and in massive limestone is probably largely retained in the rock. The short life of radon precludes any great diffusion of this gas. The complexity of the reservoir and of the movements of the hydrocarbons through it to the well make difficult the sampling of the sedimentary rocks from which crude oils and gas obtain radon.

#### EFFECTS OF RADIOACTIVITY

The chemical changes caused by radioactivity have been elucidated by Lind (29). Saturated hydrocarbons under alpha radiation are transformed into higher gaseous and liquid hydrocarbons and hydrogen. From methane are formed ethane, propane, butane, pentane, and other higher members and hydrogen. From ethane not only hydrogen is liberated but methane and liquid members are condensed at earlier stages of the reaction than with methane. The reactions of propane and butane are also described by Lind. He concludes that the lower hydrocarbons under alpha-ray bombardment evolve hydrogen and condense to higher hydrocarbons both saturated and liquid unsaturated. Radiation of higher members results in the elimination of both hydrogen and methane accompanied by condensation. When unsaturated hydrocarbons are exposed to alpha radiation, the tendency for the elimination of gaseous products is less than in the saturates, and with ethylene a liquid condensation product is obtained. The suggestion was made by Lind that if geological conditions were met where alpha radiation affected gaseous hydrocarbons, a liquid mixture of hydrocarbons similar to petroleum should be produced.

In a later discussion of this subject (30), reviewing also more recent research to which the same theory has been found applicable, the statement is made that under conditions similar to those of alpha radiation (electrical discharge through hydrocarbons), quantities of liquid sufficient for fractionation were obtained. It was found that the most abundant molecular species in these liquids were those with

double the number of carbon atoms of the original hydrocarbon. A great variety of products, in both the paraffin and olefine series, is to be expected on the basis of Lind's alpha radiation studies. From a single member of either high or low molecular weight, all other members, above and below in the hydrocarbon series, should be obtained, and the quantity of each should be distributed according to a probability curve.

The theory (31) that petroleum may be derived from gaseous hydrocarbons is contrary to the generally accepted opinion of geologists that petroleum originates chiefly from solid or semi-solid resistant organic complexes, both nitrogenous and non-nitrogenous (32). No attempt has yet been made to determine the effect of alpha radiation upon such complex compounds, but Richards (33) has shown that condensation and elimination of hydrogen proceed when solids are exposed to alpha rays and that the reaction is independent of the state of aggregation of the substance under radiation. Pertinent in this connection is the presence of ether-insoluble compounds, probably in colloidal dispersion (34), in free oil from the oil shale considered to be the source of petroleum in the Playa del Rey field, California (35). Such compounds may be the condensed products from reactions on original source material.

Objections to the reality of alpha radiation as an effective cause of chemical reactions in the generation of petroleum have been stated by Lind (30) and Brooks (36). Both authors cite the absence of hydrogen in natural gases as an objection to acceptance of the quantitative importance of such reactions. Brooks furthermore states that the presence of optically active substances in petroleum precludes the origin from gaseous hydrocarbons and considers that the absence of helium in natural gases associated with crude oils disproves any great amount of alpha radiation in petroleum.

These obstacles to the theory are not insuperable. The amount of helium produced in alpha-ray reactions is small compared to the quantity of hydrogen or hydrocarbons formed since each alpha-ray affects about 100,000 hydrocarbon molecules.<sup>5</sup> If the source material were of solid or semi-solid organic derivation and the first reactions were chiefly those resulting in condensed solids or colloids and liquids and gas, optically active substances might well be retained in the resulting

<sup>5</sup> Paneth (45) comments on the low content of helium in the gases from the Iraq and Iran oil fields and compares the deep geosynclinal sediments with the more highly radioactive sedimentary rocks, including oil- and gas-bearing strata which were derived from the degradation of granitic areas. Inasmuch as helium-bearing gases are usually rich in nitrogen, disintegration of nitrogenous organic compounds by alpha radiation may play a part in the formation of nitrogen in natural gases.

liquid mixture. Hydrogen could conceivably be lost from the natural gas associated with the crude oil by diffusion through the cap rock or by hydrogenation of the hydrocarbon compounds.

Hydrogenation has occurred under alpha radiation of hydrocarbons, but to a less extent than polymerization and condensation. With ethylene Lind found that some ethane is formed by the effect of alpha rays but that the principal reaction is one of polymerization with some elimination of hydrogen, not one of hydrogenation. The suggestion is also made (30) that hydrogenation of unsaturated hydrocarbons may be an important factor in the removal from earth gases of the hydrogen liberated by alpha radiation from hydrocarbons and water. Hydrogenation has also been proposed by Pratt (37) to explain the increase of the hydrogen-carbon ratio in the evolution of crude oils. In discussing the inorganic constituents of petroleum (38) Thomas deprecates the efficacy of nickel as a catalyst in the natural hydrogenation of crude oil, but notes the presence of molybdenum in certain ashes from petroleum and comments on its striking catalytic effect on hydrogenation. Apparently hydrogenation of the unsaturated hydrocarbons in crude oils may be an effective process in natural oil-field reservoirs through geological periods of time to the extent that hydrogen is available.

The precision of the determinations of radon and radium in the crude oils of the present investigation permits calculation of the hydrogen produced in them by alpha radiation. Emission from radon is at the rate of  $3.5 \times 10^{10}$  alpha particles per second per curie (Table III, ref. 24). Including radium A and radium C', the rate is  $3.8 \times 10^{14}$  alpha particles per hour per curie. The crude oils range from about  $0.1 \times 10^{-12}$  to  $0.4 \times 10^{-12}$  curies Rn/gm. of oil; therefore, emission is between 38 and 150 alpha particles per hour per gram of oil. Assuming uniform radioactivity in the oil, in 100 million years ( $8.7 \times 10^{11}$  hours),  $0.33 \times 10^{14}$  to  $1.3 \times 10^{14}$  alpha particles would be produced in each gram of crude oil. In the condensation of gaseous saturates, according to Lind (29), one molecule of hydrogen is formed for each ion-pair, and an average of approximately  $1.9 \times 10^5$  ion-pairs are formed per alpha particle in air. Similar ionization in the hydrocarbons would produce  $0.63 \times 10^{19}$  to  $2.5 \times 10^{19}$  molecules of hydrogen from a gram of oil in the time assumed. The corresponding volume of hydrogen at standard conditions is 0.23 to 0.92 cc. per gram of oil. The effect of radium content of the crude oils on this quantity is negligible, but under natural conditions the decomposition of radium F may be effective. If so, the volume would be increased to 0.30 to 1.2 cc.  $H_2$  per gram of oil per 100 million years.

Under the assumptions used, the chemical effect on a gaseous saturate would be small. With methane the ratio of hydrogen atoms produced to carbon atoms would be  $1/3,000$ . With undersaturated compounds the ratio of molecules reacting to ion-pairs is larger (29); therefore, radiation is more effective chemically.

The amount of hydrogen formed, however, is great enough to require explanation of its absence from usual analyses of natural gas. Hydrogenation, of course, may account for part of this deficiency but diffusion also may be an efficient process in removing hydrogen from natural gases. Experiments have shown that from a mixture of 3 per cent hydrogen and 97 per cent carbon dioxide, a gas containing 90 per cent hydrogen may be concentrated by irreversible diffusion through ball clay (39). Escape of hydrogen upward from oil fields is also suggested by the composition of the natural gas found at the base of the glacial drift in Michigan. Newcombe (40) describes shallow gas fields, particularly in those Michigan areas where important oil-bearing formations lie below the drift, and gives the hydrogen content as 25-26 per cent. Other analyses of natural gases containing hydrogen include those from Novo-Usensk, Russia (41), from Ohio (42) and from the Lima-Indiana fields (43). Precise determinations of hydrogen might prove it to be a more common constituent of natural gas in small amounts than is usually believed. If diffusion is an effective factor in its elimination from oil-field gases, hydrogen should be concentrated under less permeable formations. Hydrogen also has been found in appreciable concentrations (up to 0.006 per cent by weight) in soil gases extracted from the sediments of oil fields (44). The hydrogen content of soil gases offers a field for interesting research and is suggested as a possible method of geochemical prospecting for oil fields.<sup>6</sup>

#### CONCLUSION

In summary, the indications of quantitative effectiveness of alpha radiation, based on the radioactivity of the crude oils alone and neglecting dissolved and associated gas in the fluid of the oil-field reservoir, appear to be in harmony with former opinion. The effect of alpha particles on natural hydrocarbons would seem to be a minor reaction superimposed upon chemical changes of much greater significance produced by temperature and pressure. This conclusion, however, is far from final. If, when the natural gases accompanying oil are studied, they are found to contain considerable amounts of radon, the chem-

<sup>6</sup> "Hydrogen . . . often has been found in favorable concentration patterns over favorable structure. Hydrogen soil concentrations do not show appreciable background values, and usually display very high contrast, suggesting a unique origin."—Reference 44, page 9.

ical effects of radioactivity in the generation of petroleum may prove to be important.

This preliminary investigation suggests future research on the radioactivity of sediments and of crude oils. Paneth has clearly shown the path to follow in elucidating the causes of radioactivity in sediments. The physical characteristics of sedimentary rocks are to be correlated with the lands from which they were derived and with the conditions under which they were laid down. In his fundamental research, Lind has directed attention to the need for a more complete understanding of the chemical effects of radioactivity in the natural environment. Much remains to be done before quantitative statements can be made with confidence in answer to the many unsolved problems.

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PALEOGENE OF BARBADOS AND ITS BEARING ON  
HISTORY AND STRUCTURE OF ANTILLEAN-  
CARIBBEAN REGION<sup>1</sup>

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ABSTRACT

The writer discusses in detail the stratigraphic sequence of Barbados.  
Scotland formation (lower and middle Eocene)  
Joes River formation (mudflow of upper Eocene age)  
Oceanic formation (upper Eocene and lower Oligocene)  
Bissex Hill marl (uppermost Oligocene or lower Miocene)  
Coral rock (Pliocene-Pleistocene)

Evidence is given for the ages assigned to these formations and correlation with other parts of the Caribbean region is discussed. The importance of upper Eocene orogeny in the Caribbean region is stressed. A résumé is given of the geological history of the Antillean-Caribbean region in which it is concluded that during the Upper Cretaceous and Eocene a land or shallow-water connection existed between the Caribbean and European Mediterranean regions but that this connection was broken during the upper Eocene orogeny. A comprehensive correlation chart for the Caribbean region is presented.

INTRODUCTION

For a long time Barbados has been of great interest to geologists. The terraces in its Coral rock and its famous Radiolarian earth have formed the main subjects of interest and after these latter sediments were considered as deposits of great oceanic depth, Barbados was a proof to many geologists that abyssal deposits could, within a short time interval, be elevated to the surface. In a later period the exceptional geographical position of Barbados, and hence its importance for the successful understanding of the history and the structure of the Antillean-Caribbean region, was recognized (Lit. 51, 55).<sup>3</sup>

However, the full realization of its importance could not be ascertained as long as the age of the two older formations was not exactly known. It was only 3 years ago that H. G. Kugler and his collaborators gave a new age determination of the Oceanic formation (Lit. 34, p. 1444), and recent findings of a rich fauna of larger Foraminifera at various horizons in the Scotland formation have now enabled the writer to determine more precisely the age of this formation.

These new age determinations of the Barbados sediments allow a much better correlation with neighboring countries, especially Venezuela and Trinidad, and may contribute in elucidating some of the

<sup>1</sup> Read before the Trinidad Geological Conference, Trinidad, B.W.I., April 18-27, 1939. Manuscript received, December 14, 1939.

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<sup>3</sup> References are made to literature listed at end of this article.

main problems encountered there, notably the question of the orogenic movements which built up their mountain chains. In establishing relations between Barbados, Venezuela, and Trinidad the writer could use the knowledge acquired during his stratigraphical studies carried out in Falcón from 1927 to 1932. During these years he also became fairly well acquainted with Trinidad geology and undertook some excursions in Curaçao and Porto Rico.

Interesting relations are also shown between Barbados and the arc of the Lesser Antilles, and the writer therefore made a trip to those islands to try to substantiate the ideas formulated during the study of the Barbados Tertiary sediments: nine days (February 11-19, 1939) were spent in Martinique, a week in Guadeloupe and Grande Terre (February 20-26, 1939), eight days in St. Barthélémy (February 27-March 6, 1939) and two days in Antigua (March 7-8, 1939).

In presenting a kind of a synthesis of the southern part of the Antillean-Caribbean region, the writer wishes to state that this is undertaken entirely from a stratigraphical point of view, by drawing the conclusions from a comparison of carefully studied and correlated sections. The entirely different methods employed by Hess (Lit. 25) and Sonder (Lit. 58)—although of the greatest value—have not been utilized in this paper, as it seems more valuable for the present to see the same problems considered separately from different points of view. In discussing the relationship between the Antillean-Caribbean and the Mediterranean region the writer could use the knowledge gained while working in Morocco and Algeria from 1933 to 1936.

Also a great amount of literature has been studied, but as the work was compiled in Barbados the writer did not have at his disposal all the original publications, and had in many cases to depend on Schuchert's compilation (Lit. 55).

The stratigraphical correlation chart is presented in order that the many formation names mentioned in this paper may be more clearly understood. It is mainly based on the distribution of the larger Foraminifera as shown on the left side of the chart. In many cases small Foraminifera and Mollusca have also been used for correlation.

#### ACKNOWLEDGMENTS

The writer is much indebted to the British Union Oil Company Limited in London for giving permission to utilize in this paper some of the results of his studies carried through in Barbados from 1937 to 1940 on behalf of this company.

He also wishes to express his thanks to H. G. Kugler for allowing the use of some determinations made in the paleontological laboratory

of Trinidad Leaseholds Limited, and for his kindness in showing him many of the most important localities of Trinidad geology in 1938.

After this paper was read at the Trinidad Geological Conference, the writer had the pleasure of making excursions in Barbados with H. G. Kugler, H. H. Hess, A. G. Hutchison, and R. Rutsch, and received much help in elucidating many problems from the criticism and suggestions of these geologists.

H. D. Hedberg kindly undertook the mineralogical examination of some sand samples from the Scotland formation and allowed the use of some of his results, for which the writer is very grateful.

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#### GENERAL OUTLINE

Barbados (Fig. 1) is for its largest part ( $\frac{2}{3}$ ) covered by Pleistocene reef-limestones, known as the Coral rock. In the northern half of the island this formation has been elevated to a height of more than 335 meters and forms there a dome-like uplift, the roof of which has been partly removed by erosion. In the large semi-circular erosional window, the older formations underlying the Coral rock are largely outcropping. This region has been called the "Scotland district" (Lit. 54, pp. 9, 222) on account of its mountainous character with its highly dissected ridges and numerous ravines and valleys, which are in sharp contrast to the large undulating features of the Coral rock area.

The Scotland district offers the best exposures for the study of the older formations, which are more specially treated in the present paper. Besides this large outcrop of the older formations, there are a few smaller and isolated ones, of which only the coast section of Ragged Point in southeastern Barbados is considered here.

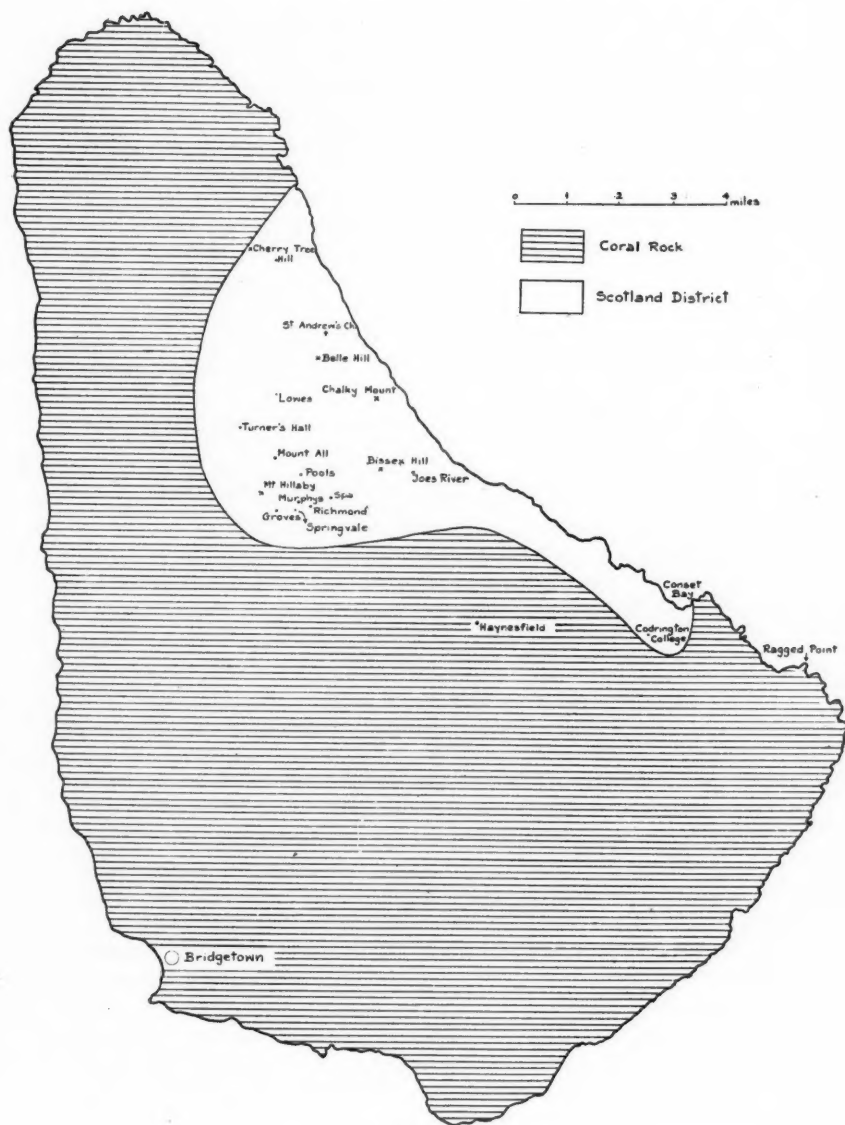


FIG. 1.—Sketch map of Barbados.

STRATIGRAPHICAL SEQUENCE IN BARBADOS  
SCOTLAND FORMATION

The oldest formation cropping out in Barbados is the Scotland formation (Schomburgk, 1847, Lit. 54, p. 534). Schomburgk included in this formation all the strata below the Coral rock, cropping out in the Scotland district. In 1890 Harrison and Jukes-Browne (Lit. 22, p. 11) separated from this formation the white chalks and Radiolarian earths, for which they proposed the name "Oceanic series."

The first attempt to subdivide the Scotland formation was made by A. Menzies, geologist of the British Union Oil Company in Barbados from 1920 to 1923. Some of his results have been published by Beeby Thompson (Lit. 65) without mentioning Menzies name, and Matley (Lit. 41) took over the information forwarded by Beeby Thompson.

The writer proposes to subdivide the Scotland formation in the following manner (from bottom to top).

## Lower Scotland formation or St. Andrew's beds (shales predominating)

Walkers beds  
Morgan Lewis beds

## Upper Scotland formation (sands predominating)

Murphys beds  
Chalky Mount beds  
Mount All beds

## LOWER SCOTLAND FORMATION OR ST. ANDREW'S BEDS

This formation is characterized by a great development of dark gray silty and sandy shales with streaks of dense greenish clay and numerous nodules and streaks of brown and red claystone, clay-ironstone and siltstone, giving to those beds a very typical aspect (claystone-shales). The silts and clays contain only rare arenaceous forams. The formation can be subdivided into two parts (from bottom to top).

*Walkers beds.*—These beds build up the ridge situated north of St. Andrew's Church and the estate houses of "Walkers" and "The River." They are the oldest beds exposed on the island, as already stated by Harrison and Jukes-Browne (Lit. 22, p. 12). The outcrops all along this ridge are excellent, but the dip is very steep and isoclinal folding makes it difficult to arrive at an exact conclusion concerning the thickness. An easily accessible section, which may be designated as the type section, is exposed on the eastern side of the cane-track leading from "The River" Estate house towards the northwest.

The Walkers beds consist of an alternation of important bodies of claystone-shales (as already described) and several larger sand bodies,

in which the individual sand beds have a thickness of 0.2-2 meters, and are again separated by claystone-shales. The sands are light brownish to light gray in color, and are mostly fine- to medium-grained, nests and layers of coarse, gritty sand being exceptional. In contradistinction to the upper Scotland sands, the sands of the Walkers beds are rarely banded or laminated, but generally occur in massive, compact beds.

Up to now, fossils have been found only at one locality in these beds: a lens (1.4 X 0.4 meters) of cemented grit and sandy limestone, enclosed in 3 meters of coarse-bedded sands, furnished common *Discocyclinas* and very rare small "Nummulites."

The thickness exposed in the type sections is about 240 meters, but a well, drilled through 650 meters of these beds, did not reach their bottom.

The Walkers beds are clearly overlain by the Morgan Lewis beds, but the contact is generally disturbed because the plastic claystone-shales of the Morgan Lewis beds are sheared off from the more rigid Walkers beds.

*Morgan Lewis beds.*—The type section has been chosen on the ridge immediately east of the Morgan Lewis River (northeast of Morgan Lewis Estate House), where a flatly north-dipping series is excellently exposed, showing the passage towards the overlying Murphys beds. The beds can also well be studied at the bottom of the Lowes Ridge section (see p. 1557).

The Morgan Lewis beds consist almost entirely of claystone shales (as previously described), in which sand beds are extremely rare. On the other hand fine whitish sand is everywhere present in small lenses, streaks, and films. The deeper part of these claystone-shales encloses in the highly disturbed Boscobelle segment a zone of coarse-bedded white sands whose exact stratigraphic position can not be elucidated, however, on account of the complicated structure. The upper 150 meters of the Morgan Lewis beds in many places contain one or two beds of somewhat cemented coarse grit (of 0.5-1.5 meters thickness), which at two places furnished rare *Discocyclinas* and small "Nummulites." Towards the top of the Morgan Lewis beds more and more thin sand beds appear, forming a clear transition towards the overlying sandy Murphys beds.

In the southern part of the Scotland district, south of Murphys and Chalky Mount, the Morgan Lewis beds become more sandy.

In the type section 190 meters are exposed, in the Lowes Ridge section 160 meters, but the total thickness nearly reaches 500 meters.

## UPPER SCOTLAND FORMATION

*Murphys beds.*—At the type section exposed in the Murphys River near Murphys Village, the lower part consists of an alternation of well bedded light brownish, fine to coarse sands and gray or lilac-colored silts. The sands show false-bedding and many of them contain thin carbonaceous bands, giving them a characteristic striated and laminated aspect. Above, a monotonous alternation of gray silts and fine whitish sands follows, containing short lenses of hard, light gray red-weathering, sandy and carbonaceous limestone, in places barren, in other places rich in Bryozoa and *Discocyclina*. The silts do not contain smaller Foraminifera, but some gritty nests furnished the writer with a well preserved fauna of larger Foraminifera consisting of several species of *Discocyclina* (*Discocyclina*), *Nummulites*, *Operculina* and *Amphistegina*. Near the top of the Murphys beds are more yellowish, banded carbonaceous sands, forming the transition toward the overlying Chalky Mount grits.

In general the Murphys beds are more sandy than in the type section; they form a typical transitional phase between the silts of the Morgan Lewis beds and the coarse, gritty sands of the Chalky Mount beds.

It is most probable that the large blocks of hard, gray sandy limestone, commonly found in the Turner's Hall River and other places, and from which Trechmann obtained fresh-water mollusks (Lit. 68, p. 484, fossil bed "a"), have their origin in the Murphys beds, where they are supposed to form similar lenses to the Bryozoa-*Discocyclina*-bearing limestones previously mentioned. This opinion has recently been confirmed by the finding of such a lens in place in the Murphys beds approximately 720 meters south of St. Andrew's Church. The lens is 16 meters long, swelling abruptly to a thickness of approximately 5 meters and consists of gray, impure, somewhat sandy limestone with badly preserved large Mollusca. While many of the blocks in the Turner's Hall River strongly resemble this rock lithologically and are very probably derived from the Murphys beds, some others contain gritty and conglomeratic nests, suggesting a possible origin from the Chalky Mount beds. Fossil collections from all the different blocks will have to decide in the future if they are all being derived from the only horizon of the Murphys beds or from different horizons of the upper Scotland formation.

The thickness of the Murphys beds varies between 65 and 100 meters.

*Chalky Mount beds.*—At Chalky Mount and in the Spa-Murphys area, the lower half consists of massive to coarse-bedded, whitish to

yellowish, friable, coarse, gritty sands, in some places enclosing concretionary lenses of hard cemented calcareous grit and alternating with a few well bedded finer-grained sands. These "Lower Grits" attain a thickness of more than 100 meters at Chalky Mount, and of more than 50 meters on the Spa peak.

The grits are composed of irregularly shaped, commonly corroded, mostly subangular to edge-rounded, rarely well rounded quartz grains, which vary in size from fine sand to pebbles of a maximum diameter of 1 centimeter. The quartz is mostly colorless and transparent, more rarely milky and blue. Rolled quartz crystals are common.

Irregular lenses and ledges of fine conglomerate are enclosed in the grits at various horizons, and although they may occur at the base, the presence of a "base conglomerate," which suggests an erosional unconformity at the base of the Chalky Mount beds, must be denied.

At the eastern end of Chalky Mount, there is at the base a conglomerate about 5 meters thick, but near the summit of the mountain this conglomerate no longer exists. Another conglomerate, about 3-4 meters thick, occurs about 50 meters above the base of the Chalky Mount beds, and a third conglomerate, approximately 1.5 meters thick, about 70 meters above the base.

At the Spa peak, one finds a small conglomeratic lens of 1 meter thickness about 2 meters above the base of the Chalky Mount beds. The most important conglomerate, from which Trechmann (Lit. 68) obtained his fossils, lies between 17 and 23 meters above the base, its two ledges—separated by a grit layer—reaching a thickness of 5.3 meters. Some more conglomeratic grits occur 36 meters above the base.

The conglomerates are built up by more numerous and larger quartz pebbles, which, however, rarely exceed a length of 2.5 centimeters. As in the grits, the pebbles are irregularly shaped, many corroded, mostly subangular to edge-rounded, rarely well rounded and mostly consist of colorless and transparent, more rarely of milky and blue quartz. Rolled quartz crystals up to a length of 1.5 centimeters are not uncommon. Besides this quartz, apparently derived from quartz veins, the writer observed a few better rounded pebbles of a reddish, hard, clastic quartz rock. The conglomeratic aspect of the Chalky Mount conglomerates is, for a great part, due to the frequency of buff-colored, globular, marble-like marlstone concretions of a diameter of 3-15 millimeters. Besides these and the quartz pebbles, there are also some well rounded pebbles of red and brown claystone and irregular pieces of brown sandstone, calcareous sandstone, calcareous grit with shell fragments, sandy limestone with *Lithothamnium* and *Amphistegina* and characteristic brown sandy limestone full

of small *Nummulites* and *Operculina*. These rocks, as for instance the last mentioned, might be partly of foreign origin, or some of them might have been broken off from the sediments under formation by the currents bringing the quartz pebbles.<sup>4</sup>

At Chalky Mount only the conglomerates contain rare and poorly preserved mollusk-shells, while at the Spa peak and near Pools the whole mass of the "Lower Grits" carries mollusk shells and larger Foraminifera (*Discocyclina*, *Nummulites*, and *Operculina*). In the conglomerates, where the fossils are more frequent, they are apparently rolled and worn, but in the grits many of the very delicate shells are preserved with their finest sculpture, proving that the fauna—at least in its larger part—has to be considered as autochthonous. However, the presence of the aforementioned pieces of Nummulitic limestone makes it probable that one might also expect some reworked pieces amongst the isolated fossils.

At Spa and between Murphys and Pools, the "Lower Grits" are overlain by a peculiar sediment, to which the term "gritty silt" has been applied. It consists of a massive, dark gray or brownish silt, rich in mostly angular or poorly rounded quartz grains up to a diameter of 5-7 millimeters. These "gritty silts," reaching a thickness of 30 meters at Spa, are rich in well preserved Mollusca and larger Foraminifera (*Discocyclina*, *Nummulites*, *Operculina*, *Amphistegina*, et cetera).

At the western side of Chalky Mount these gritty silts are still well developed in the middle part of the Chalky Mount beds, and are rich in mollusks and *Discocyclina*, but towards the east they are more and more replaced by well bedded whitish and purplish sands and silts, and by coarse-bedded white gritty sands, enclosing large concretionary lenses of hard calcareous grit. The thickness of the middle Chalky Mount beds attains 50-55 meters at Chalky Mount.

At Spa and Chalky Mount the uppermost part of the Chalky Mount beds consists of an alternation of white, friable, coarse, gritty sands, white medium-grained sands with gritty nests, banded sands and gray, more or less gritty silts. At both places, towards the base, there is a characteristic bed of hard, cemented conglomeratic calcareous grit of approximately 1 meter thickness, containing small echinids at Chalky Mount. At this locality the white grits also enclose some large concretionary lenses of hard cemented grit, weathering out in the form of a rosary.

The upper Chalky Mount beds have furnished the writer at Chalky Mount with some *Discocyclina*, *Nummulites*, *Operculina*, while

<sup>4</sup> Similar occurrences which prove this hypothesis more clearly have been observed by the writer in the Lower Cretaceous Flysch of the Algerian Coastal Atlas, which lithologically shows a striking resemblance to the Scotland formation of Barbados.

at Spa they seem to be barren; the thickness is between 32 and 38 meters at Chalky Mount, 22 meters at Spa.

The Chalky Mount beds pass gradually to the overlying Mount All beds, the boundary being chosen on top of the uppermost occurrence of grit.

In the northern part of the Scotland district the Chalky Mount beds are not as well developed as at the type locality and at Spa. At Belle Hill there is a conglomerate near the base, which can be traced as far as the western slope of the Lowes Ridge, but the compact mass of the "Lower Grits" is more and more replaced by finer sands and silts. In the Lowes Ridge section another conglomerate appears—between 45 and 60 meters above the base—in five individual ledges and some smaller lenses in the middle of a sequence of gray and lilac-colored silts.

From Lowes westward, the grits are almost completely replaced by finer sands and silts and in Turner's Hall it is no longer possible to separate Murphys and Chalky Mount beds.

At Ragged Point in southern Barbados the lithology of the Chalky Mount beds differs from the one of the type section in that the grits are cemented.

The total thickness of the Chalky Mount beds varies between 90 and 200 meters. The notable increase of the thickness towards the southeast shows that the source furnishing the clastic material was located southeast of Barbados and not to the west, as suggested by Hess (Lit. 25, p. 89).

*Mount All beds.*—In the area around Mount All, the Mount All beds are highly folded and contorted, making a study of their sequence very puzzling. On the other side, a very good section is exposed on the Lowes Ridge, not only showing 230 meters of Mount All beds, but also the whole sequence of the Scotland formation as far down as the upper part of the Morgan Lewis beds.<sup>5</sup>

The Mount All beds consist of a uniform alternation of gray and lilac-colored silty and sandy shales, some with brown ferruginous streaks, brownish thinly bedded sands, red-brownish carbonaceous banded and foliated sands (similar to Murphys beds) and white, massive, friable, medium- to coarse-grained sands, some of them a little gritty. The sands by far predominate over the silts. As in the Murphys beds, there are rare lenses of gray calcareous sandstone or sandy limestone, some of it glauconitic and containing bands rich in Bryozoa and *Discocyclus*.

In the outcrop, the Mount All beds can hardly be distinguished

<sup>5</sup> This section has been sampled for heavy-mineral studies kindly undertaken for the writer by H. Hedberg.

from the Murphys beds, and as fossils are exceptionally rare in both subdivisions, it is ordinarily only the position above or below the Chalky Mount beds which allows one to distinguish between them.

Up to the present fossils have been obtained from only four localities, of which three come from the lenses of sandy limestone previously described. The fourth, from brown loose sands, furnished the writer with interesting smaller Foraminifera and abundant discoidal *Discocyclina*; also common *Discocyclina* of the asterocycline type.

The thickness measured in the Lowes Ridge section is 230 meters, but the sequence there is not complete on the top. From a well drilled in the upper Mount All valley, the total thickness of the Mount All beds seems to be as much as 500 meters.

The Mount All beds form the youngest part of the Scotland formation. After their deposit, important orogenic movements occurred, which caused the emergence of Barbados and brought the Scotland sediments into a highly complicated structure, with thrust faults striking southwest-northeast, the movement of the thrust being directed from northwest to southeast.

#### AGE OF THE SCOTLAND FORMATION

Up to the present time the age of the Scotland beds has been determined solely by the fauna from the Chalky Mount conglomerates. This fauna was first studied by R. Bullen Newton in 1922, but his report has not been published (see Lit. 41). The locality from which most of his fossils were derived and which is indicated as "2 miles SW. of Bissex Hill," seems to be Spa. Bullen Newton arrived at the conclusion that the "fauna indicates an age that may be summed up in the compound term, *Bartonian-Priabonian*."

Trechmann (Lit. 68, p. 487) in 1925 arrived at a more precise conclusion in stating that the fauna "has much affinity with the Claiborne facies of Alabama, the Eocene of Nigeria found at Ameki, and the Lutetian and probably more to the Bartonian of Europe. The horizon of the fauna seems to be high in the middle Eocene, or rather low in the upper Eocene (Lutetian-Auversian-Bartonian)."

The fauna of larger Foraminifera, discovered by the writer in 1937 in all the three subdivisions of the upper Scotland formation, seems to confirm the middle Eocene affinities already mentioned by Trechmann. At the present time the writer's conclusions can be based only on generic determinations, but he soon hopes to have at his disposal the determinations of Mrs. M. de Cizancourt in Paris and T. W. Vaughan in Washington, who kindly undertook the study of our Nummulites and Orbitoides.

The fauna is as follows.

*Murphys beds*

*Discocyclina* (*Discocyclina*), several species

*Discocyclina* (*Asterocyclina*) ?, very rare

*Nummulites* sp.

*Operculina* sp.

*Amphistegina* cf. *lopeztrigoi* Palmer

*Chalky Mount beds*

*Discocyclina* (*Discocyclina*), several species

*Nummulites* sp.

*Operculina* sp.

*Amphistegina* cf. *lopeztrigoi* Palmer

*Mount All beds*

*Discocyclina* (*Discocyclina*), several species

*Discocyclina* (*Asterocyclina*) sp.

*Amphistegina* cf. *lopeztrigoi* Palmer

The most striking character of this fauna is the complete absence of the genus *Lepidocyclina*, so abundant in the upper Eocene of the whole Antillean-Caribbean region. An age older than the upper Eocene is therefore indicated for the upper Scotland formation. On the other hand the presence of the subgenus *Asterocyclina*, which up to now was reported in America only from the upper Eocene, but which, according to a verbal communication of Th. F. Grimsdale (9/3/1938) occurs in the middle Eocene of Mexico,<sup>6</sup> indicates that the upper Scotland formation must be placed in the middle Eocene, an opinion with which Trechmann's aforementioned statement is not in contradiction. The abundance of *Amphistegina* of the group of *A. lopeztrigoi* Palmer, which has been described from the middle Eocene of Cuba and Mexico (Lit. 81, p. 233) supports a middle Eocene age of the upper Scotland formation.

In a recent publication (Lit. 85, p. 240) R. Rutsch described the occurrence of the gastropod genus *Tubulostium* from the upper Scotland formation of Barbados (Murphys and Chalky Mount beds). The author states that the presence of this genus makes it certain that the upper Scotland formation has to be placed in the Eocene, but leaves it open, whether it should be considered as middle or upper Eocene, the resemblance of the Barbados *Tubulostia* with those of the Boca de Serpiente formation of Trinidad rather pointing to upper

<sup>6</sup> In Europe the first appearance of *Asterocyclina* occurs in the Ypresian (upper part of lower Eocene) of the Vicentine, while in the Aquitaine and in Morocco the subgenus is known only from the Lutetian (middle Eocene) (Lit. 56, pp. 100-101).

Eocene. However, since the publication of Rutsch's paper, the writer has sent him more and better preserved material, which enabled Rutsch now to state, that the *species from Barbados is definitely different from the one of the upper Eocene of Trinidad* (letter of Dr. Rutsch to the writer, dated 15/5/40). This again indicates for the upper Scotland formation an age older than upper Eocene, and most probably middle Eocene. The lower Scotland formation, which underlies the upper Scotland in continuity and transition, then has to be regarded as of lower Eocene age, an opinion for which some support is furnished in the chapter on the Joes River beds (see p. 1572).

#### TYPE OF SEDIMENTATION AND ORIGIN OF CLASTIC MATERIAL

The Scotland formation throughout is apparently the deposit of a shallow, muddy sea, traversed by numerous currents, with localized ingress of fresh water probably derived from smaller torrents and almost purely clastic sedimentation. Its great thickness indicates that the region in which it was laid down was rapidly and continuously subsiding.

The Scotland formation shows the typical aspects of the Flysch facies, that is, thick and uniform alternation of shales and sands, difficult to subdivide on account of the absence of marked lithological changes and the scarcity of fossils.<sup>7</sup>

In considering the problem concerning the source of the terrigenous material contained in the Scotland formation, the writer is fortunate enough to be able to use some of the interesting results of the petrographical studies recently carried through by H. Hedberg.

Besides the quartz, which forms the major element of the sands, feldspar is common in 109 of a total of 113 samples (this in contradiction to Matley's statement, Lit 41). Among the heavy residues Hedberg recognized:

	Abundance in Individual Samples	Number of Samples in Which Present
Black opaques (largely ilmenite)	abundant to common	113/113
Leucoxene	common to rare	113/113
Zircon	common to rare	112/113
Tourmaline	rare	89/113
Garnet	common to rare	102/113
Staurolite	rare	103/113
Sillimanite	very rare	11/113
Kyanite	rare	63/113
Andalusite	rare	8/113
Topaz	rare	42/113
Glaucothane	very rare	5/113

<sup>7</sup> The Flysch is a typical orogenic sediment deposited along the borders of rapidly subsiding geosynclines. The terrigenous sedimentation is alimented by narrow island cordilleras named geanticlines, whose relief is continuously renewed by the orogenic forces (see Gignoux's masterly exposition, Lit. 17, pp. 4, 12-15, 552-553, and the excellent recent article of Tercier, Lit. 63).

	<i>Abundance in Individual Samples</i>	<i>Number of Samples in Which Present</i>
Epidote	common to rare	62/113
Zoisite-clinozoisite	abundant to rare	61/113
Rutile	rare	91/113
Anatase	very rare	7/113
Brookite	very rare	4/113
Chloritoid	common to rare	90/113
Hypersthene	fairly common to rare	9/113
Augite	fairly common to rare	5/113
Titanite	rare	17/113
Corundum	very rare	1/113

The presence of garnet, staurolite, sillimanite, kyanite, andalusite, glaucophane, epidote, zoisite-clinozoisite, chloritoid, and titanite in the mineral assemblage indicates that it was probably in large part derived from metamorphic rocks of dynamo-thermal origin. The presence of topaz suggests contact zones among the source rocks. The quartz pebbles of the Chalky Mount beds seem most probably derived from vein quartz (see p. 1555).

Special mention must be made of the occurrence of pyroclastic pyroxenes (hypersthene and augite), whose volcanic origin, according to Hedberg, is "clearly indicated by glass borders on the euhedral crystals."

Of the 10 samples in which pyroclastic pyroxenes occur, 7 are from the Chalky Mount grits and conglomerates. The remaining 3 come from a sandy-gritty intercalation in the claystone shales of the Morgan Lewis beds. This rather suggests that the pyroclastic minerals have been brought together with the grits by the currents, and therefore would be derived from reworked pyroclastic rocks, occurring amongst the metamorphic rocks from which the bulk of the accompanying minerals comes. A derivation from ash falls of near-by volcanoes, contemporaneous with the Scotland sedimentation, does not seem probable to the writer, owing to the fact that the pyroclastic pyroxenes are "fairly common" in only three of the samples and rare in all the others. Moreover, it would be peculiar if such ash falls should always have coincided with a gritty phase of the Scotland sedimentation.

Taking into account the Flysch character of the Scotland sediments (see p. 1560) and the fact that the Chalky Mount grits notably increase in thickness in a southeasterly direction (see p. 1557) it has to be assumed that the clastic material contained in the Scotland formation was derived from an emerging geanticlinal ridge passing south of Barbados and mostly built up by metamorphic rocks traversed by quartz veins and possibly including bodies of acid and basic igneous rocks. The writer thinks that this cordillera was a forerunner of the important chain of metamorphic rocks represented to-day by the

Northern Range of Trinidad, the Caribbean Coast Range of northern Venezuela and some smaller remnants, as the islands of Tobago and Margarita.

According to Rutten (Lit. 50, p. 829), the Venezuelan coast range near Puerto Cabello and La Guaira is largely built up by gneisses and rarer mica schists, belonging partly to the epi-zone, mostly to the meso-zone and possibly also to the kata-zone of metamorphism. S. E. Aguerrevere and G. Zuloaga (Lit. 1, pp. 7 and 8) think that the advanced metamorphism shown in the Cordillera de la Costa proper is partly due to regional metamorphism and partly to—mainly acid—igneous intrusions. They state that the core of this range is chiefly composed of a granitic gneiss and an augen gneiss formed by injections, *lit par lit*, of a granitic magma into a laminar rock of sedimentary origin. Basic intrusions are also mentioned from the Cordillera de la Costa (*loc. cit.*, p. 9).

The southern part of the Caribbean Coast Range, called Serrania del Interior, is built up by two cycles of metamorphosed sediments of probably Mesozoic age, but the metamorphism is not as advanced as in the Cordillera de la Costa proper. Basic igneous intrusions are found within both cycles (*loc. cit.*, p. 19).

Higher metamorphic rocks are also outcropping on the Isla Margarita, according to a verbal communication received from H. Hess (20/7/1939).

In the Northern Range of Trinidad there are two systems of rocks: the older and more metamorphic one consists mainly of phyllites with abundant lenses and veins of quartz and interbedded crystalline limestones. The discovery of upper Tithonian ammonites by A. G. Hutchison (Lit. 26) proves that this system represents Jurassic. The younger system is composed of less metamorphosed, calcareous, shaly and sandy sediments, which have furnished C. T. Trechmann (Lit. 71 and 64) with fossils of Upper Cretaceous age. The presence of quartz veins in these rocks (Lit. 36, p. 2, stop 2) shows that the vein-quartz injection is post-Upper Cretaceous. An augite andesite with associated tuffs<sup>8</sup> is found at Sans Souci, altering the surrounding Cretaceous sediments (Lit. 39, 71 and 36).

The metamorphic rocks building up the northern part of Tobago consist, according to Trechmann (Lit. 70, p. 482), mainly of talc-mica schists and schistose grits containing many quartz veins and inclusions. Basic igneous rocks (epidiorites, dolerites, gabbros) form more than half of the island (*loc. cit.*, p. 481).

Thus, from the foregoing outline it seems possible that the clastic

<sup>8</sup> According to A. G. Hutchison's statement made during the Trinidad Geological Conference, April, 1939.

material of the Scotland formation is derived from a forerunner of the actual mountain chain extending from the Caribbean Coast Range of Venezuela to the Northern Range of Trinidad and to Tobago, although in these last mentioned islands the rocks show a lesser degree of metamorphism than is required by the mineral content of the Scotland formation. But it could easily be assumed that by an axial rise, higher metamorphic beds came to the surface in the sector of the chain, passing south of Barbados. On the other hand, the abundance of quartz lenses and veins occurring in the Northern Range of Trinidad and in Tobago, would form an excellent source for the Chalky Mount grits of Barbados. Quartz crystals, as are frequently found in the Chalky Mount beds in a rolled state, are equally common in the Northern Range of Trinidad, as the writer saw for himself in 1938 while on an excursion with H. G. Kugler.

The reason why pebbles other than quartz are so rare in the Chalky Mount conglomerates may be that the softer pebbles have been completely smashed during transport, while only the hard pebbles of vein quartz could resist. However, it may be mentioned again that the writer has found, besides the vein-quartz pebbles, some rare pebbles of clastic quartzite, which could be derived from the quartzitic sandstones interbedded with the schists in the Northern Range. Besides, Trechmann (Lit. 41) has discovered at Sunbeam "a small piece of crystalline limestone (coarse-grained marble), like that of the Northern Range of Trinidad or Isle of Pines."

Trechmann (Lit. 71, p. 174) and Dighton Thomas (Lit. 64, p. 179) conclude that the metamorphism of the rocks building up the Northern Range of Trinidad is due to orogenic movements which took place subsequent to the deposition of the Upper Cretaceous sediments and which led to the erection of this mountain chain. The writer agrees with these authors in considering the alteration of the Mesozoic sediments of the Northern Range as a dynamo-metamorphism acquired during the erection of this mountain chain, but he thinks that another important cause of the metamorphism is the syntectonic injection of vein quartz, which might be derived from a deep-seated intrusion of a granitic magma. It is obvious that the vein-quartz injection is of post-Upper Cretaceous age, and as, on the other hand, this vein quartz seems also to be contained as pebbles in the Scotland formation of Barbados of lower and middle Eocene age, we must conclude that the orogenesis causing the metamorphism and leading to the erection and denudation of the Northern Range and its eastern and western prolongations must have taken place near the Cretaceous-Eocene boundary.

Summarizing the statements made concerning the source of the

clastic material contained in the Flysch facies of the Scotland formation, it seems most probable that it is derived from the metamorphic rocks of an island cordillera which, from the Northern Range of Trinidad, extended to Tobago and passed south of Barbados into the Atlantic.

#### CORRELATION

*Trinidad.*—The only formation in Trinidad which resembles the Scotland formation lithologically is the Pointe-à-Pierre formation, consisting of an alternation of variegated silts and shales, flaggy sandstones and massive grits. On the basis of this lithological similarity, which also calls for a similar origin, H. G. Kugler has correlated the Pointe à Pierre formation with the Scotland formation of Barbados (Lit. 34, p. 1444).

During the session of the Trinidad Geological Conference in April, 1939, however, H. G. Kugler (Lit. 37) expressed the opinion that the Pointe à Pierre formation may be of Cretaceous age, thus taking up the idea of V. C. Illing (Lit. 28, p. 12). To-day most of the Trinidad geologists favor again a lower or middle Eocene age of the Pointe à Pierre formation, a view supported now by paleontological evidence (for instance, *Discocyclina* sp.).

Concerning the source from which the Pointe à Pierre formation received its clastic material, an unmistakable indication is furnished by the fact that the Pointe à Pierre formation reaches a great development in the Central Range, but is unknown in southern Trinidad. The source of its clastic material therefore seems to lie in the north, pointing again to the Northern Range.

From this it seems that the Pointe à Pierre formation of central Trinidad could be defined as an Eocene Flysch facies deposited along the southern slope of the Northern Range, the Scotland formation as an Eocene Flysch facies deposited along the northern slope of an eastern prolongation of the Northern Range. The striking difference in the heavy mineral assemblages of the two formations could be explained by the assumption that the poor assemblage of the Pointe à Pierre formation was derived from the lesser metamorphosed beds outcropping actually in the Northern Range of Trinidad, whereas the rich assemblage of the Scotland formation was derived from higher metamorphic beds, coming to the surface towards the east on account of an axial rise.

The orogenic movement, which caused the emergence of the Northern Range at the Cretaceous-Eocene boundary, seems to have been confined to a narrow belt along this chain, because already in southern Trinidad an unconformity between Cretaceous and Eocene seems to

be absent, as is suggested by the occurrence of uppermost Cretaceous and lowermost Eocene sediments. In fact the upper Tarouba formation (upper Argiline Hobson Clay, Lizard Spring beds) contains a fauna of small Foraminifera almost identical with the one of the Tamesi formation (= Velasco shales) of Mexico, which according to the latest information available is considered as Danian (Lit. 84, p. 91). On the other hand, the Soldado (= Marac) formation has been correlated with the Midway by Maury (Lit. 83) and recently Rutsch has confirmed this age determination (Lit. 35, p. 19) and has even pointed out that the Soldado-Marac fauna probably represents Montian (oral communication, June, 1939). Therefore it seems that, during the time the Northern Range was rising from the sea at the Cretaceous-Eocene boundary, there was continuous marine sedimentation in southern Trinidad. However, the emergence of the Northern Range seems to be reflected in the sedimentation of southern Trinidad by the appearance of a sandy and slightly conglomeratic shallow-water facies in the Soldado formation, following the clayey-marly sedimentation of the upper Tarouba formation.

*Eastern Venezuela.*<sup>8a</sup>—According to H. Hedberg's valuable paper on the Rio Querecual section, lower and middle Eocene seems to be missing in eastern Venezuela, the "Paleocene" being directly overlain by the upper Eocene (Lit. 23, pl. 9). However, on several occasions Hedberg expressed the view to the writer, that parts of the Santa Anita and the Merecure formations might represent lower or middle Eocene. This opinion seems partly to be confirmed by Hedberg's recent discovery of an orbitoid bed, containing *Asterocyclina*, in the uppermost part of the Santa Anita formation on the Rio Querecual (Hedberg's letter of 4/3/40).

*Isla Margarita.*<sup>8a</sup>—During the last meeting of the Trinidad Geological Conference in April, 1939, C. Gonzalez de Juana made the interesting communication that he had seen an orbitoid-bearing sandstone formation on the island of Margarita, off the north coast of Venezuela. More detailed observations have recently been made by H. Hedberg, who writes the following on the Eocene section of Isla Margarita (letter dated 4/3/40).

Coarse pebble and cobble conglomerates at the base, grading upward into a sandstone and shale series with a minor amount of grits intercalated. Found abundant *Discocyclina* in the lower part of the sandstone-shale series. I rather imagine that this Margarita section is equivalent to some part of your Scotland beds.

<sup>8a</sup> The writer is gratefully indebted to H. Hedberg for giving him permission to mention some of his recent observations made in eastern Venezuela and on Isla Margarita.

The writer agrees with H. Hedberg's last statement and hopes that the latter will soon be able to give further details about the paleontology and the mineralogy of this interesting formation and its relation to the metamorphic beds cropping out on the same island.

Isla Margarita seems to belong to a similar but slightly different facies zone from Barbados, the paleogeographic elements being from south to north the following.

Orinoco Basin—Trinidad  
Caribbean Coast Range—Northern Range of Trinidad-Tobago  
Isla Margarita (with metamorphic basement)  
Barbados (basement unknown, but presumably Cretaceous)  
Curaçao Ridge—arc of the Lesser Antilles

*Northwestern Venezuela.*—An excellent correlation is possible with the Maracaibo Basin, where there is—conformably interbedded between uppermost Cretaceous and upper Eocene—a thick and uniform alternation of quartz sandstones, quartzites, shales, and sandy shales. Clay-ironstone is common and coal seams are found through the whole formation, but are especially numerous near the base. These deposits, which reach the immense thickness of 2,500 meters, are very difficult to subdivide on account of the scarcity of fossils and the frequent lateral facies changes; they have been named Guasare formation, La Sierra sandstone, Paso Diablo formation, Mostrencos formation on the western side of the Maracaibo Lake (Lit. 24) and Misoa-Trujillo formation on the eastern side (Lit. 62). The lithological similarity between these formations—which the writer has studied in central Falcón and Lara—and the Scotland formation is striking, the only difference being that in Venezuela the sands are mostly transformed into hard quartzitic sandstone, and the silts into hard silty shales.

The ages of the two formations correspond as well: in Barbados the upper Scotland formation has—according to its orbitoid fauna—to be attributed to the middle Eocene; the lower Scotland, being in transition with the upper Scotland, to the lower Eocene. In Venezuela, the lower and middle Eocene age of the Misoa Trujillo formation and its western equivalents is mainly based on the fact that at its base it is found in transition with the Mita Juan and Rio de Oro formations of uppermost Cretaceous age (Lit. 24, p. 86, and Lit. 31, p. 48), while at its top it passes by transition to the Pauji shales and the Mene Grande formation, both undoubtedly of upper Eocene age (Lit. 62 and 56).

This indirect correlation is supported by the presence of a mollusk fauna in the Guasare formation, which correlates it with the Soldado formation of Trinidad, of Midway age (Lit. 48). With this the stratigraphical position of the Guasare formation at the base of the sand formation is in perfect agreement.

The Misoa Trujillo formation can be followed from Maracaibo through the states of Lara and Falcón—where it is called Mojino quartzites (Lit. 21, p. 189) and Paraiso beds—as far as the eastern border of the Paraguaná uplift; here it disappears under the younger sediments of east Falcón. The most easterly occurrence of the Misoa-Trujillo formation seems to be the one mentioned by Kehrer on the northern foot of the Caribbean Coastal Range between El Palito and Urama (Lit. 30, p. 63).

Where the contact between the shales of the Upper Cretaceous and the sands of the lower Eocene can be observed on the western border of the Maracaibo Basin and in Tachira, it seems to be strictly conformable and transitional, some smaller sandstone beds already appearing in the Mito Juan and Rio de Oro formations. However, the appearance of a sand formation of the enormous thickness of 2,500 meters on top of a pure shale formation, is not only explained by admitting that sedimentation has changed from the bathyal type to the neritic and estuarine type, but it seems obvious that a source for the clastic material and the coal contained in the Misoa Trujillo formation must have arisen, which did not exist during the time of entirely shaly-calcareous deposition of the Upper Cretaceous epoch.

Where was the source of this clastic material and how did it originate?

In the highly mountainous country which Venezuela presents today, the conception can at once be excluded that the arrival of abundant clastic material in the north Andean geosyncline is due to a positive movement of the stable Guayana Shield, but it seems natural to admit that the source of this clastic material was created by some precursory orogenic movement preluding the following paroxysm.

An emergence of the Cordillera de Mérida at the end of the Cretaceous period does not seem probable, since, according to Kehrer (Lit. 31) and Kündig (Lit. 38, p. 31), the outcrops in this mountain range seem to prove a strict conformity and transition at the Cretaceous-Eocene boundary.<sup>9</sup>

Wiedenmayer asserts that the Sierra de Perijá was folded up dur-

<sup>9</sup> However, the writer would like to draw attention to the fact that conformity and transition on one side, unconformity on the other side, are often found very close together in geosynclinal basins traversed by geanticlinal ridges.

The writer not long ago had the opportunity to study such conditions in the coastal Atlas of Algeria, where, during the Miocene and Pliocene epochs, several movements occurred on the Dahra geanticline, leading to unconformities, whereas in the closely lying Chélif geosyncline there was continuous sedimentation. In the perfect outcrops of these semidesert countries it was possible to follow from the ridge the decreasing unconformity step by step to the point where it dies out in the geosynclinal basin. Such slight unconformities can naturally be detected only by detail mapping supported by exact stratigraphical studies, and would easily be obliterated by succeeding orogenic movements.

ing the lower Eocene, because "lower middle Eocene is seen overlapping on an eroded Cretaceous surface in western Mara district" (Lit. 80, p. 222).

The hypothesis which seems most probable to the writer is, that the Cordillera de la Costa was rising from the sea at the close of the Cretaceous period. Most geologists agree that this mountain chain is the prolongation of the Northern Range of Trinidad, which, as we have already seen, seems to have suffered an orogenesis at the Cretaceous-Eocene boundary, accompanied by a metamorphism of its Cretaceous and Jurassic sediments.

S. E. Aguerrevere and Zuloaga (Lit. 1) make it seem probable that the largest part of the metamorphic rocks which build up the Cordillera de la Costa has to be considered as metamorphosed Cretaceous, especially the "Caracas group," which shows the same sequence of beds as the unaltered Cretaceous sediments in the area on the west. The important contribution of Kehrer (Lit. 30, pp. 59-60), who, in the eastern part of Lara, could clearly observe the transition from normal to metamorphosed Cretaceous sediments, can leave but little doubt that the opinion expressed by the Venezuelan geologists is correct.

The hypothesis that the Cordillera de la Costa had suffered an orogenesis accompanied by metamorphism at the close of the Cretaceous period, whereas the Cordillera de Mérida was still under water, would give us a sound explanation for the fact that the Cretaceous sediments are represented by their normal unaltered facies in the Cordillera de Mérida, and by a metamorphic one in the Cordillera de la Costa.

The probability of this hypothesis is enhanced when one considers that in the metamorphosed Cordillera de la Costa, quartz-bearing rocks which could furnish the clastic material contained in the Misoa Trujillo formation were lying on top, while in the Cordillera de Mérida several hundred meters of shaly and calcareous Cretaceous sediments would have to be eroded before any quartz-bearing rocks could be reached.

*Dutch Leeward Islands (Curaçao, Bonaire, Aruba).*—A correlation of the Scotland formation with the Midden Curaçao formation of Curaçao and the Soebi Blanco conglomerate of Bonaire seems to be indicated, but before entering into a description of these formations it is, for a clearer understanding, necessary to give a short summary of the geology of these islands (see Lit. 43, 46, 47, 53, 78, 79).

The oldest formation cropping out on the three Dutch islands is the Diabas-schist-tuff formation, consisting of a thick alternation of various diabases, various porphyrites, various diabas- and porphy-

rite-tuffs (in places containing Radiolaria and Foraminifera), diabas- and porphyrite-breccias and conglomerates, dark schists and shales, black cherts and radiolarites, chert breccias, silicious limestones and dark gray dense limestones in thin beds. This formation has been named Aruba formation in Aruba, Diabas formation and Knip formation in Curaçao and Washikemba formation in Bonaire, where it reaches the enormous thickness of at least 5,000 meters (see Lit. 47, p. 9).

The Diabas-schist-tuff formation is thought to be of Upper Cretaceous age, and the great resemblance existing between the cherts of the Knip and Washikemba formations and those of the Venezuelan La Luna formation suggests that the latter formation might be comprised in the Diabas-schist-tuff formation of the Dutch Leeward Islands.

The formation seems to have been laid down under geosynclinal conditions in a rapidly subsiding sea, whose sedimentation was alimented by submarine volcanoes furnishing the various lava flows and the loose material contained in the tuffs and volcanic agglomerates.

The Diabas-schist-tuff formation is unconformably overlain in Curaçao by the Seroe Teintje limestone containing a rudistid fauna considered of Campanian-Maestrichtian age (Lit. 47, p. 32). In Bonaire the corresponding beds, unconformably overlying the Washikemba formation, have been named Rincon formation and reach a thickness of 200 meters. They consist of limestones, conglomeratic limestones and conglomerates. The limestones contain many ill-preserved fossils: gastropods, bivalves, nautiloids of the genus *Herzoglossa*, corals, Foraminifera and *Lithothamnium*. The presence of the genus *Globotruncana* indicates Cretaceous, while the occurrence of the genus *Orbitoides* shows that these beds belong to the uppermost Cretaceous (Campanian-Maestrichtian) and enables one to correlate them with a part of the Havana formation of Cuba and the Blue Mountain formation of Jamaica, both containing the genus *Orbitoides*.

The Seroe Teintje limestone and the Rincon formation have to be considered as a near-shore facies deposited along a ridge which was created during the preceding orogenesis. A first intrusion of granodiorite probably accompanied this orogenesis, as is suggested by the presence of rare granodiorite pebbles in the Rincon conglomerates, besides the more common pebbles of Washikemba rocks, as cherts, diabases, porphyrites and tuffs.

After the deposition of these uppermost Cretaceous formations, the Dutch Leeward Islands suffered a strong orogenesis which led to

the intrusion of an important diorite batholith in Aruba and caused strong contact metamorphism of the rocks of the older Diabas-schist-tuff formation, changing the diabases into uralite diabases, the tuffs into hornblende schists. Westermann (Lit. 79, p. 30) has ably demonstrated that the contact metamorphism has been accompanied by a contemporaneous dynamo-metamorphism, because "the hornblende needles and fibres, resulting from the contact metamorphism, lie parallel in most of the hornblendized tuffs" . . . . "Moreover, the banded structure in these rocks must have come into existence, thanks to a folding process, during the invasion of vein material, the latter connected with the diorite intrusion." So Westermann comes to the conclusion "that the diorite batholith intruded during the folding of the older formation." The same is proved by the strike of the various dikes deriving from the batholith, which coincides with the strike of the schistose and tuff rocks.

Similar intrusions of quartz diorites are known from northwestern Curaçao, while in Bonaire only one dike of porphyritic quartz diorite could be recognized (Lit. 47, p. 29). Similar plutonic rocks are also reported from the small Venezuelan islands lying between Bonaire and Grenada. The observation of S. E. Aguerrevere and Lopez (Lit. 2), that in Gran Roque the quartz diorite is intruded from below into diabase, is of the greatest importance, showing that conditions here were similar to those present in Aruba and Curaçao. Moreover, it is a certain proof that the Venezuelan islands from Los Roques to Los Hermanos are the prolongation of the Dutch Leeward Islands (as already assumed by Rutten, Lit. 51, p. 105), and have to be considered as the ruins of an important mountain chain folded up at the close of the Cretaceous period.

Unconformably overlying the Diabas formation, the Knip formation and the Seroe Teintje limestone, we find in Curaçao the Midden Curaçao formation (Lit. 78). It consists of a basal conglomerate zone, attaining in central Curaçao a thickness of 200-550 meters, of a middle sandstone zone and an upper shale zone, the two latter together reaching a thickness of 700 meters. The conglomerates have a calcareous cement and contain fragments of *Lithothamnium*, Mollusca and Foraminifera. The pebbles are mostly derived from the underlying Diabas-, Knip-, and Seroe-Teintje formations, but there are also foreign constituents, such as amphibolites, mica schists and microcline gneisses. The sandstones, chiefly composed of angular to rounded quartz, mica and rounded chert grains, are in some places very calcareous and alternate with limestones.

In Bonaire, the corresponding formation has been named Soebi

Blanco conglomerate (Lit. 47). It attains a thickness of 400 meters and consists of coarse conglomerates with calcareous cement and of conglomeratic calcareous sandstones. Besides pebbles derived from the underlying Washikemba and Rincon formations, there is an abundance of foreign pebbles such as granodiorites, gneisses, quartzites, amphibolites, etc.

The age of the Midden Curaçao beds and the Soebi Blanco conglomerate is indicated by the fact that they are younger than the Seroe Teintje limestone and the Rincon formation of uppermost Cretaceous age, younger also than the granodiorite intrusions, of which they contain pebbles, and older than the upper Eocene Seroe di Cueba (Lit. 53) and Seroe Montagne limestones (Lit. 47), by which they are overlain unconformably. A lower or middle Eocene age therefore has to be attributed to the Midden Curaçao formation and the Seroe Blanco conglomerate, an opinion corroborated by Trechmann's examination of Midden Curaçao fossils (Lit. 47, pp. 37-38).

It follows from this that the Midden Curaçao formation and the Soebi Blanco conglomerate have to be considered as approximate time equivalents of the Scotland formation of Barbados and the Misoa-Trujillo formation of northwestern Venezuela. The lithology also shows similarity as all these formations are built up by clastic material derived from terrestrial denudation. But there is a very marked difference: whereas the Scotland formation is entirely built up of fine clastic material derived mostly from metamorphic rocks, the Midden Curaçao beds and the Soebi Blanco conglomerate contain abundant pebbles of volcanic and plutonic rocks.

L. Rutten and the other explorers of the Dutch Leeward Islands expressed the opinion that the foreign pebbles of the Midden Curaçao beds and the Soebi Blanco conglomerate were derived from the Venezuelan Coast Range and more especially from the hinterland of Puerto Cabello (Lit. 50, p. 1022). The writer can not agree with this hypothesis, because the lower-middle Eocene Misoa-Trujillo formation cropping out opposite Curaçao in Falcón and Lara is of the usual fine clastic type and does not contain any larger pebbles. The facts that the Seroe Blanco conglomerate contains many pebbles from Bonaire itself, and that among the foreign pebbles there are granodiorites and amphibolites which agree well with rocks from Aruba (Lit. 47, p. 37) make it probable that these pebbles are derived from an important mountain chain, folded up at the close of the Cretaceous period, and of which the Dutch Leeward Islands and the Venezuelan islands form only small remnants.

On the other hand, it might not be impossible that the source of

some of the fine clastic material contained in the Misoa-Trujillo formation of northwestern Venezuela, might be the Curaçao Ridge.

*Antillean arc and Greater Antilles.*—On the islands to-day forming the arc of the Lesser Antilles no sediments intermediate in age between the Upper Cretaceous chalk of Antigua (?) and the upper Eocene St. Bartholomew formation are known. This seems to be true also in Puerto Rico. On the other hand, middle Eocene is known in Hispaniola as the Plaisance limestone, reaching a thickness of 1,000 meters and resting unconformably on volcanic rocks (Lit. 55, pp. 453-54).

In Jamaica the middle Eocene also seems to be represented by a calcareous facies, the "Yellow Limestone," whereas the clastic Richmond formation, which has been attributed by Trechmann to the lower Eocene, forms the detritus of the Cretaceous volcanic formations, reworked by a shallow sea (Lit. 55, p. 426).

The writer would not close this chapter without drawing attention to the strikingly similar conditions which existed during the latter part of the Cretaceous and the beginning of the Tertiary period, on the Dutch Leeward Islands on one side and the Greater Antilles on the other. Both regions show:

Upper Cretaceous sediments largely interstratified with volcanic rocks and their tuffs  
A possible unconformity within the Upper Cretaceous  
An uppermost Cretaceous, in which coral-rudistid- and orbitoid-bearing reef limestones are largely developed  
An important orogenesis at the Cretaceous-Eocene boundary, causing the intrusion of important masses of granodioritic rocks

#### JOES RIVER BEDS

Harrison and Jukes-Browne described the youngest member of the Scotland formation as "a great thickness of bluish-grey clay containing small quantities of petroleum" (Lit. 22, p. 13). These beds have later been named "Joes River Clay" by Menzies (Lit. 65 and 41), who still included them in the Scotland formation and who seems to have been the first to recognize that they have to be considered as the products of mud volcanoes.

As the deposits under discussion are really not clays, the writer proposes to change the name into "Joes River beds," and to consider them for the present as an independent unit between the Scotland formation and the Oceanic formation, although some observations suggest that they might have to be included later in the Oceanic formation.

The name is derived from the Joes River valley, where these deposits cover a large area and are outcropping in several deeply intersected ravines. Still better exposures exist in the area immediately

west of the Joes River valley, in the "barranco"-like ravines of the Spa and Richmond estates. Another area of large development is in the Mount Hillaby syncline, on both sides of the Mount All Ridge.

The bulk of the Joes River beds consist of dark gray silts with numerous angular, sharply delimited inclusions of greenish clay up to walnut size, giving them the typical aspect of "pebbly silts." Angular pebbles and irregular nests and wisps of dark brown tar sand are also commonly included. The pebbly silts are traversed by numerous cleavage planes, showing slickensiding and containing free inspissated oil.

At the base of the formation the pebbly silts generally show no stratification, and in a chaotic manner include numerous irregular pieces of brown claystone, angular boulders, and very large, sharply delimited blocks of dark brown tar sand. Pieces of black lustrous manjak are also fairly common.

Going upward in the formation, layers of well bedded silts and tar sands (in places containing manjak) become more and more numerous, causing a slight stratification of the beds. However, these tar-sand lenses and layers are generally short and reach a larger size only in the upper part of the formation. But even here the bedding is not well defined and besides the tar-sand layers, pebbles and blocks of tar sand persist to the top of the formation.

A sequence of well bedded silts and tar sands in the upper part of the Joes River beds of the Mount All Ridge furnished some smaller Foraminifera, and in the western branch of the Spa River H. G. Kugler—on a recent excursion with the writer—discovered well preserved marine Mollusca in the upper stratified part of the Joes River beds. The fossils, among which a large long-tailed *Leda* is most common, occur in layers of tar sand, as well as in the pebbly silts and in lenses of gray knobby marlstone containing free oil.<sup>10</sup> The fossiliferous zone in the western branch of the Spa River is about 60 meters thick, beginning at about 300 meters above the base of the Joes River beds and overlain by about 90 meters of non-fossiliferous pebbly silts.

The mostly chaotic texture, the presence of typical pebbly silts and the enormous content of inspissated oil, leave no doubt that the Joes River beds have to be considered as the result of an important mud-volcano activity (compare Lit. 33). The presence of a stratification—however ill defined—and of a certainly autochthonous fauna of marine Mollusca in the upper part of the Joes River beds, suggests that the mud-flows have partly occurred under the cover of a shallow sea.

<sup>10</sup> H. G. Kugler drew the writer's attention to the fact that these marlstones look very similar lithologically to those of Freemans Bay, Trinidad.

The rocks composing the Joes River mud-flows are derived from the various parts of the Scotland formation, including blocks of conglomeratic Chalky Mount grits, but the bulk of the silts with their conspicuous brown claystone certainly originates from the lower Scotland formation. The green clay pebbles, which contain some arenaceous Foraminifera, apparently are derived from the streaks of greenish clay so commonly interstratified in the dark gray silts of the lower Scotland formation (see p. 1552).<sup>11</sup>

Among the blocks contained in the Joes River mud-flows, only one type of rock has been encountered up to the present which does not crop out at the surface in Barbados. These blocks are of hard, well bedded, gray, somewhat glauconitic, sandy and gritty limestones, rich in *Lithothamnium*, *Discocyclina* (*Discocyclina*), *Nummulites* and *Operculina*. The flat-shaped limestone blocks are often oil-impregnated and some of them contain angular inclusions of greenish silt, giving them a brecciated aspect. These blocks are very numerous in the uppermost Mount All River and the ravines at the southern slope of the Mount All Ridge. The writer supposes that these blocks might be derived from a formation similar in age to the *Pellatispirella* limestone forming the roof of the Soldado formation on Soldado rock (Lit. 35, pp. 214 and 216).<sup>12</sup>

Hess (Lit. 25, p. 89) expressed the opinion that the Joes River beds might be considered as a submarine landslide caused during the down-buckling of his "tectogene." The writer, although admitting that the mud-flows—after being extruded—might have been affected by submarine landsliding, holds that the hypothesis proposed by Hess can not explain some of the main features of the Joes River beds, for instance their oil impregnation and the fact that they are mostly derived from the sediments of the lower Scotland formation, even including beds which are not cropping out to-day.

The writer has no more doubts about the correctness of the interpretation of the Joes River beds as mud-flows since he has seen the

<sup>11</sup> The fact that the streaks of greenish clay furnish the pebbles, and the silts of the Lower Scotland formation the *matrix* of the pebbly silts, may be explained by a different mechanical reaction during the extrusion of the mud-flows. The porous silts, mixed with gas, oil and water, ascended in a viscous pulpy state, while the more compact clay was broken into pebbles. In a similar way some of the tar sands must have come up in a fluid state and were redeposited in wisps, lenses and layers, while others were extruded as solid, sharply delimited pebbles, blocks, or boulders.

<sup>12</sup> This opinion is now fully confirmed by a letter (dated July 19, 1939) from T. W. Vaughan, who writes: "I rather think that I am giving you the information that you most wish. Your numbers S. 45, 91 and 95-99 are Lower Eocene, representing a horizon about equivalent to the *Discocyclina* and '*Pellatispirella*' limestone of Soldado Rock, Trinidad. This determination, I believe, confirms your surmise as to the geologic age of the blocks derived from Joes River mud-flow."

recent mud-flows of Iros Bay on the south coast of Trinidad (Lit. 36, p. 18, stop 70).

The thickness of the Joes River beds has, up to the present, been exactly determined only in the south flank of the Murphys anticline (western branch of Spa River), where it reaches the enormous size of more than 450 meters. In the crest of the anticline, on the other hand, the thickness is reduced to approximately 10 meters, while in the Mount Hillaby syncline, following the Murphys anticline in the north, the thickness is very considerable. These conditions could be explained by the following alternatives.

1. There have been mud-flow vents north and south of the area occupied to-day by the Murphys anticline. The fact that the blocks of lower Eocene limestone (see p. 1574) are very numerous north of the anticline, but seem to be entirely missing south of the anticline, speaks in favor of this hypothesis.

2. The mud-flows have been deposited in an equal thickness over the whole area and have been eroded in the crest of the Murphys anticline previous to the deposition of the Oceanic formation. In this case one would expect a conglomeratic facies at the base of the Oceanic formation in the crest of the Murphys anticline. This, however, is not the case, the Oceanics being developed there in their usual facies.

3. The mud-flows have been extruded during the upfolding and through the crest of the Murphys anticline and from there flowed downwards into the synclines on either side, where they have accumulated in great thickness. This hypothesis, which is favored by the writer, is made probable by the fact that near the crest of the Murphys anticline a steeply dipping manjak vein occurs, which was mined until 1919 by R. H. Emtage.

Through the courtesy of this gentleman is offered the information upon the conditions encountered in the manjak mines of Springvale Estate (see also Lit. 13). The manjak occurs here in one continuous vein, which has been followed in the mine over a distance of 120 meters along the strike, without reaching the end. The strike of the vein is approximately northeast, that is, more or less parallel with the general strike in this area. The dip is approximately 45 degrees near the surface, but gradually becomes steeper until at a depth of 100 meters it reaches more than 80 degrees. The average thickness of the vein is 0.5 meter varying from 0.15 to 1 meter, and "horses" of clay and sand are in places included in the manjak. The wall formation is composed chiefly of sand and a small proportion of clay, is much disturbed and shows little sign of stratification, while at the surface—according to the writer's observations—the St. Andrew's beds consist

of a regular, well bedded alternation of sands and silts and form a gently folded anticlinal core, cut by small crestal faults only. Below the 45-meter level gas was encountered in the manjak vein, and at 100 meters this became strong enough to blow up mud as high as 4 meters from the bottom of the shaft and extinguish the safety lamps.

These conditions suggest the Springvale manjak vein to be the innermost filling of a larger mud-flow vent.

Another manjak vein was mined a little farther north, at Groves (Lit. 13), in the north flank of the Murphys anticline. Owing to the fact that in recent time this area has been affected by a big landslide, no accurate statement about the structural position of this vein can be made. However, it seems highly possible that this vein is in connection with an important strike fault, which the writer has mapped on both sides of the Groves landslide, and along which a migration of tarry oil can be recognized.

The hypothesis seems therefore permissible that the Joes River mud-flows north of the Murphys anticline were extruded through the Groves vent, while those south of the Murphys anticline were derived from the Springvale vent. This would explain the presence of blocks of lower Eocene grit (see p. 1574) only to the north of the Murphys anticline.

The Joes River beds lie with an angular unconformity on an eroded surface of Scotland sediments: in the north flank of the Murphys anticline they overlap from Mount All beds on Chalky Mount beds and finally on Murphys beds. In the same area faults can be observed, involving the Scotland sediments, but without disturbing the Joes River mud-flows. This clearly demonstrates that an orogenic movement preceded the deposition of the Joes River beds. On the other hand, there are faults—as for instance the aforementioned Groves fault—which affect the Scotland and the Joes River sediments, but do not disturb the overlying Oceanic beds, which overlap these faults.

These observations clearly demonstrate that during the whole time of the extrusion of the Joes River mud-flows orogenic movements occurred, and it is obvious that the orogenesis—by creating disturbances in the Scotland sediments—was the cause of the gas pressure captured in the oil reservoirs being released, which allowed it to break through the roof of the overlying formations and extrude the mud-flows.

Therefore it can be stated that the strong orogenesis occurring between the deposition of the Scotland and the Oceanic formations initiated the sedimentary volcanism in Barbados. In a later chapter

(pp. 1584-1590) we shall see to what geological age this important orogenesis has to be attributed.

## OCEANIC FORMATION

## GENERAL DESCRIPTION AND TYPE SECTION

The term "Oceanics" was introduced in 1890 by Harrison and Jukes-Browne (Lit. 22) to designate the formation of white chalk and Radiolarian earth intermediate between Scotland formation and Coral rock. In 1892 these authors published a very exhaustive paper on the Oceanic deposits (Lit. 29, b) containing, apart from a good description of many sections, some very detailed and highly interesting studies on the minute structure and the chemical composition of the Oceanic rocks and of the organic remains found in them. These authors were assisted in their work by the best specialists of that time, such as J. Murray, W. Hill, H. B. Brady, and C. A. Raisin.

In referring to this fundamental and classical work on the Oceanic deposits, the writer contents himself with describing the section of Mount Hillaby which well exposes a great thickness of the formation and therefore should be designated as the type section.

The best profile which has been measured and sampled in detail by the writer is exposed in the southern flank of the Mount Hillaby syncline, in the deeply intersected ravine which descends from near the summit on the eastern slope of Mount Hillaby, and on the ridge limiting this ravine in the south. A nearly uninterrupted succession of beds can be studied here, and the highest unexposed beds of the synclinal core were made accessible by 13 test pits (of a depth of 3 meters) placed in distances of 10-15 meters along the cane-track leading from the northern to the southern peak of Mount Hillaby.

The following succession is shown from bottom to top.

1. Approximately 1 meter dark gray silt with greenish clay pebbles, boulders of brown tar sand and blocks of marlstone containing black tarry oil on cleavage planes. This bed forms the top of the Joes River mud-flow and encloses a nest of greenish slickensided non-foraminiferal clay 0.5-0.6 meter below the base of the Oceanics.
2. 0.1 meter greenish slickensided clay, similar to the foregoing, but containing well preserved Foraminifera of the genera *Globigerina*, *Gyroidina*, *Globorotalia*, *Anomalina*, *Nodosaria*, *Cristellaria* and some small fish teeth (base of Oceanic formation).
3. 5 meters white compact marlstone rich in *Globigerina* and other Foraminifera (among them *Hantkenina alabamensis* Cushman), some echinid spines and small fish teeth.
4. 1.5 meters gray *Globigerina* marl rich in other Foraminifera (among them *Hantkenina alabamensis*), Radiolaria and some echinid spines and small fish teeth.
5. 18 meters regular alternation of white, thinly bedded siliceous marlstones and white, gray or greenish *Globigerina*-Radiolaria marls containing frequent other Foraminifera (among them *Hantkenina alabamensis*) and rare echinid spines and small fish teeth. The Radiolaria are in most of the samples already more numerous than the *Globigerinidae*.
6. 3.5 meters alternation of white siliceous marlstone and grayish marly Radiolarian earth containing numerous Foraminifera, but very few *Globigerinidae* and rare small fish teeth.

Era-Group	Period-System	Epoch-Series	Markers principally used for correlation												U. S. A. Gulf Coast	Mexico	Panama
			Orbitoides s.l.	Discoscypha	Alatrosphyra	Alatrosphyra	gillispadi	isolepidin	gillispadi	isolepidin	gillispadi	isolepidin	gillispadi	isolepidin			
Cenozoic	Quaternary	Pleistocene													Anastasia coquina (and Key Largo coral <sup>(24)</sup> )	Oyster beds and Reynosa conglomerates	Raised beach deposits
	Miocene	Pliocene													Caloosahatchee F.	Eruptive conglomerate S <sup>th</sup> Maria Tafelia beds	Limon Bocas F.
		upper													Choctawhatchee F.		Toro 1 <sup>st</sup>
		middle													Shoal River F. Oak Grove sand	Tuxpan F.	Gatun F. upper middle lower
		lower													Chipola F.		Caimito F.
	Oligocene	upper													Tampa 1 <sup>st</sup> Catahoula F.	Coazintla beds ?	Emperador 1 <sup>st</sup>
															Non marine formation (sands and shales)	San Rafael beds ?	Culebra F. upper
		middle													Chickasawhay F. Bucatanua F. Byram marl	Meson F.	Bohio congl.
		lower													Glendon limestone Marianna 1 <sup>st</sup> Forest Hill beds Red Bluff clay	Huasteca F. (Alazan)	
	Eocene	upper													Ocala 1 <sup>st</sup> Yazoo clay Moody's marl (incl. Gosport sand)	Chapapote F. Tantoyuca F.	Tranquilla Shales David = Hall Chagres 1 <sup>st</sup>
															Lisbon F. Cook Mountain F. Sparta sand Cane River F.	Guayabal F. Temopol F.	Bucaru F.
		middle													Wilcox (Salt Mountain) 1 <sup>st</sup> Midway	Aragon F. Tanilajas F.	
		lower															
Mesozoic	Cretaceous	upper														Tamesi F. (= Velasco)	
															Navarro F.	Escondido	
															Taylor F.	Mendez F.	
															Austin Chalk	San Felipe F.	
	Cretaceous	lower													Eagle Ford F. Woodbine F. Washita F. Fredericksburg F. Glenrose F. Trinity F.	Aguanueva F. El Abra 1 <sup>st</sup> Tamaulipas 1 <sup>st</sup>	
	Cretaceous	lower															


● Rock forming in Venezuela, Colombia, Ecuador, Peru, Mexico.

STRATIGRAPHICAL CORRELATION CHART

### Stratigraphical Correlation Chart of the Tertiary and Creta

Ecuador	Peru	Colombia		Zulia	
		Middle Magdalena Valley	Lower Magdalena Valley and Coastal	Maracaibo West	Maracaibo East
Tablazo F. (cf. Peru)	Negritos Tablazo Lobitos Tablazo Talara Tablazo Mancora Tablazo	Magdalena F.	La Popa Coral 1 <sup>st</sup>	Milagro F.	
Canoa F.	Sechura F.	Mesa F.	Barranquilla F.	Onia beds	
Bajada F.	Tumbez F. Cardalitos F. Upper Zorritos F. Variegated beds	Hondá F.	Real F.	Usiacuri F. Upper Tubera F. (zones P-S of Andersen) (Cartagena beds) Lower Tubera F. (zones M-O of Andersen)	La Villa F. La Puerta F.
	Lower Zorritos F.	La Ciria fossil horizon	Las Perdices F.	Los Ranchos F.	Lagunillas F.
San Pedro coast sandstone	Heath F.	Colorado F.	Tapaliza shales	El Taúso F.	La Rosa F.
Ancon Point F.	Mancora F.	Mugrosa fossil horizon	Sandstones, congl. and limestones with large Lepidocyclinae		Icofeá F.
	Chirra F.	Mugrosa F.	Monifos shales (with nummulitic plates)		"Eulepidina" limestone of Quebrada Manuelita Paloma alta shales and Cerro Venado congl.
Socorro F.	Saman F. (incl. Yerdun grits)	Los Corrales fossil horizon	Poso F.		Ambrosio F. Menegrande F.
Clay pebble beds	Talara F.	Toro F.	Arroyo Hondo beds	Orumo F.	Pauji F.
	Restin shale			Mostrencos F.	Upper Misao Trujillo F.
Middle Grits	Parinas sandstone				
Guayaquil limestone	Pale shales				
	Salina F.				
	Negritos F.	Lisama F.		Paso Diablo F. Guasare F.	Lower Misao Trujillo F.
		Umir F.		Rio de Oro F. Mito Juan F.	Mito Juan Shales
		Guadalupe F.		Colon Shale	Colon Shale
		Villeta F.		La Luna limestone	La Luna limestone
				Cogollo limestone	Cogollo limestone
		Suarez F.		Rio Negro conglomerate	Tamon F.

# ceous Formations of the Antillean-Caribbean Region.

Venezuela			Trinidad		
Falcón basin		Orinoco basin			
Central Falcón	East Falcón	Eastern Venezuela	Central Range	Naparima Area	Southern Trinidad
	Casa Ventura beds	Llanos beds	Whiteland sand	Tableland deposits	Tableland deposits (Megatherium sands)
Upper Cadore F. (San Gregorio horizon)	Cumarebo F. Punta Gavilan beds	Quiriquire F	Matura beds (in Northern depression)	?	La Brea beds
La Vela F (and Coro conglomerate)	Ojo de Agua F. (?) A1 c. Clays Agusallado Clays, zone A2 Capadare lsite	Manicure - Cubagua beds	Talparo F. Springvale fossil bed	Morne Enfer beds (Upper Moruga F.)	
Urumaco - Caujarao F.	A1a clays Inf beds Punguapana lsite of Roraima	 Santa Ines F.	Brasso sands Los Atayos conglomerate	Naparima clay St. Croix F.	Upper Forest clay
Socorro sands	As Clays (Aguido beds)		Brasso Clays Guacacara - Siche lsites		Forest sands
Querales shales	Solito - Curamichale sands As - As Clays				Lower Forest clay
Cerro Pelado F.	As - As Clays				Cruse sands & clays
Aguaclara F.	marine zone (A) As Clays El Mene Acosta sands Guarabal egl.	Carapita F.	upper and middle ?	Upper Cipero Marl (Princetown Marl)	Morne Diablo beds
San Luis limestone			lower ?	?	Cipero Silt (Bamboo Clay)
Pedregal-Payaya shales	Docaina lsite Montero lsite		?	Lower Cipero Marl (?)	?
Churuguará beds	Churuguará beds and Tacamire sandstone		?		
Jarital shales	Tacamire shales and Guayabal marls				
Taca F.	Cerro Campana lsite	Peñas Blancas lsites (Merecura F.?)	Mount Moriah F.	Mount Moriah F.	Mount Moriah F.
Tupure Shales	Cerro Misión Shales				
Paraiso beds & Mojino-quartzites			Pointe-à-Pierre F.		
			Dunmore Hill marls ?		
			?		Soldado F.
		San Antonio F.	C <sup>o</sup> Cerazon beds		
		Caracas member	Tarouba F	Tarouba F	Lizard Spring beds
		San Juan sandstone		Namulus sandstone	
		San Antonio F.	Chert Hill beds		
			Moromoceras lsites		
		Querecual F.	?		
			Sabina lsites & Stack rock lsites		
		El Canfil F. (Bergantin beds)	Hoplites & Diatoloceras lsites		
			Maridale beds & Orbitolites lsites		
		Barranquin F.	Belemnite Marls of Cuche River		

## Lesser Antilles

STRATIGRAPHICAL CORRELATION CHART (continued)

Greater Antilles				Age Stage	Epoch Series	Period System	Era Group
Porto Rico	Hispaniola	Jamaica	Cuba				
San Juan F	Coral rock	Coral rock	Coral limestone	Pleistocene	Quaternary	Cenozoic	
	Las Matas F.	Manchioneal F	Matanzas F	Calabrian			
				Astian Plaisancian			
	Cerro de Sal F			Pontian			
	Port au Prince beds	Bowden F.	La Cruz Marl and Manzanilla F	Tortonian	Miocene		
	Gurabo F. Cercado F.	Las Cañobas F.		Helvetian			
	Quebradillas 1st	Baitoa F. M <sup>me</sup> Joie F.		?	Burdigalian		
Los Puertos 1st	Cevicos 1st		Güines 1st	Aquitanian	Oligocene		
Cibao 1st	?	Cobre 1st	Cojimar F.	Chattian			
Lares 1st	Tabera F.	Monsague 1st	Miegypsina zone	Rupelian			
San Sebastian shales		Montpellier 1st	Beds with large Lepidocyclina				
			Adelina Marls				
			Principe F	Wemmelian			
	Orbitoidal limestone	Chapelton F	Bejucal F.	Ledian			
	Plaisance limestone	Yellow limestone	Jicotea beds ?	Lutétian	Eocene		
		Richmond F	Universidad F.	Ypresian			
			Capdevila F	Landenian			
Intrusion of Quartzdiorite	Intrusion of Quartzdiorite	Intrusion of Granodiorite		Montian	Paleocene		
				Danian			
Older Series	Sierra F.	Blue Mountain F.		Maestrichtian	Upper		
				Campanian			
			Havana F.	Santonian			
				Coniacian			
				Turonian			
	Sandstones, shales, limestones and Radiolaria cherts.			Cenomanian	Lower		
				Albian			
			Aptychus F. (Viñales 1st) (Artemisa 1st)	Aptian			
				Barremian			
			unconformable on Upper Jurassic	Neocomian s.str.			

with the collaboration of  
Mrs Dorothy Palmer.

- (The beds 1 to 6 are exposed on the steep northern wall of the ravine; the following beds in the ravine itself. Between beds 5 and 7 a minor fault occurs.)
7. 7 meters coarse-bedded white siliceous Radiolaria-bearing marlstone with two layers (of 0.2 and 0.4 meter) and two thin streaks of fine clastic volcanic tuff.
  8. 18 meters badly exposed zone, showing coarse-bedded white siliceous Radiolaria-bearing marlstones and gray foraminiferal Radiolarian earth.
  9. 26 meters greenish Radiolarian earth with some hard siliceous streaks. Foraminifera (including a *Hantkenina*) are rare in this zone.
  10. 0.4 meter greenish fine clastic volcanic tuff.
  11. 9 meters white-weathering greenish Radiolarian earth with rusty films and some harder streaks. Foraminifera, including *Hantkenina alabamensis*, are common, small fish teeth rare.
  12. 15 meters well bedded white siliceous Radiolaria-bearing marlstones with a lilac-colored fine clastic volcanic tuff (0.3 meters), 3 meters above the base.
  13. 7.5 meters white marly, somewhat foraminiferal Radiolarian earth with ledges of siliceous marlstone and a thin streak of fine clastic volcanic tuff (0.05 meter), approximately 2 meters above the base. Small fish teeth and Foraminifera are common, amongst them *Hantkenina alabamensis*.
  14. 5.5 meters alternation of white, somewhat foraminiferal Radiolarian earth (*Hantkenina alabamensis*) with 4 well marked ledges (0.4-0.5 meter) of violet, banded, fine clastic volcanic tuffs.
  15. 5 meters white marly, slightly foraminiferal Radiolarian earth with a few ledges of white siliceous marlstone.
  16. 1.5 meter white hard, compact siliceous marlstone with a band (0.1 meter) of fine clastic volcanic tuff, 0.6 meter above the base.
  17. 6 meters white marly, slightly foraminiferal Radiolarian earth with a double marlstone bed on top.  
(From bed 7 to bed 17 the section follows the ravine; from here upwards, the ridge immediately south of the ravine.)
  18. 25 meters olive-greenish marly Radiolarian earth with some whitish siliceous marlstones in the middle. Foraminifera, amongst which is *Hantkenina alabamensis*, are common, but more numerous towards the top; small fish teeth are rare.
  19. 0.5-1 meter white siliceous marlstone, passing towards the top into a fine clastic volcanic tuff (0.1 meter).
  20. 1.5 meters olive-greenish marly Radiolarian earth with some Foraminifera, amongst them *Hantkenina alabamensis*, and small fish teeth.
  21. 0.2 meter reddish fine clastic volcanic tuff.
  22. 6 meters olive-greenish marly, highly foraminiferal Radiolarian earth with small white calcite nodules. Foraminifera including *Hantkenina alabamensis* are frequent and varied, but Globigerinidae are rare. Small fish teeth are common.
  23. 2 meters white, compact siliceous marlstone with bands of fine clastic volcanic tuff.
  24. 4.5 meters olive-greenish marly, foraminiferal Radiolarian earth with 4 ledges of whitish knobby somewhat tuffaceous marlstones. Foraminifera including *Hantkenina alabamensis* are common, but Globigerinidae rare. Small fish teeth are common.
  25. 0.5 meter olive-greenish to white striated marlstone with bands of fine clastic volcanic tuff.
  26. 5 meters olive-greenish slightly foraminiferal Radiolarian earth. Foraminifera including *Hantkenina alabamensis* are common, small fish teeth rare.
  27. 0.1 meter reddish fine clastic volcanic tuff.
  28. 15 meters cream-colored Radiolarian earth with red and black skins on bedding planes and cleavages. (These beds have been described as "red argillaceous earth" by Jukes-Browne and Harrison (Lit. 29 b), and compared with the "red clays" of modern oceanic depth. However, the pits located in this zone in the core of the Mount Hillaby syncline, clearly showed that this red clay is a superficial product of weathering, never\* attaining a thickness of more than 0.3-1 meter and in all the pits directly underlain by the creamy Radiolarian earth. The pit-line has equally proved that the volcanic tuff beds—called volcanic mudstones by Jukes-Browne and Harrison—which form the highest summit of Mount Hillaby, do not overlie the red-weathering Radiolarian earth, but are the equivalent of beds 23 and 25, which, from underneath the red-weathering Radiolarian earth, rise again in the northwest flank of the Mount Hillaby syncline.)

\* This applies only to Mount Hillaby and not to the other localities from which the red argillaceous earth has been reported and which have not been investigated yet by the writer.

The total thickness of the Oceanic beds exposed at Mount Hillaby is 190 meters (=620 feet compared with 320-350 feet estimated by Jukes-Browne and Harrison, *Lit.* 29b, p. 210).

The writer can not agree with the opinion expressed by Jukes-Browne and Harrison (*Lit.* 29b, p. 213) that the top beds at Mount Hillaby represent the youngest member of the Oceanic formation. In the vast outcrops of Oceanic beds occurring between Conssets Bay and Codrington College the bulk of the white Radiolarian earth is overlain by a yellowish Globigerina marl, which is well exposed on the slopes immediately north and southeast of Codrington College and is directly overlain by Coral rock forming the terrace on which the College stands. Jukes-Browne and Harrison mentioned this marl (*Lit.* 29b, p. 205) and compared it with the foraminiferal marls "below the red clays on Mount Hillaby" (*Lit.* 29b, p. 214), probably corresponding to beds 22-26 of the type section given (p. 1583). This correlation, however, can not be admitted, as the marl at Codrington is a pure Globigerina marl rich in other Foraminifera, but with a complete absence of Radiolaria, while the beds which should correspond at Mount Hillaby consist of Radiolarian earth, rich in Foraminifera, but with an almost complete absence of Globigerinidae. The writer therefore considers the "Codrington College marl" as younger than the Radiolaria-bearing beds of Mount Hillaby, for which the name "Mount Hillaby beds" is proposed.

In a footpass 350 meters southeast of Codrington College a mud-flow appears just at the base of the Codrington College marl, separating it from the bulk of the Radiolarian earth.

The Oceanic formation lies with a strong angular unconformity on the older formations. It is found on the Joes River mud-flows, where these deposits are present, and in some places, as for instance in the Mount Hillaby section previously described (see p. 1583), there does not seem to be a sharp break between the two deposits: even in Bed No. 1 nests of greenish clay appear within typical mud-flows, which above pass to similar-looking green clays (Bed No. 2), containing well preserved Foraminifera. This green clay passes by transition to the foraminiferal chalks (Bed No. 3) of the true Oceanic formation. On the other hand—as mentioned previously (p. 1576)—there are in the south flank of the Mount Hillaby syncline (or the north flank of the Murphys anticline), faults which affect the Scotland and the Joes River sediments but do not disturb the overlying Oceanic beds which overlap these faults. These conditions seem to be contradictory, but they can be understood if one assumes that during the deposition of the Joes River mud-flows orogenic movements continued, but ceased

at the beginning of Oceanic sedimentation which uninterruptedly followed in places the Joes River sedimentation. In other places, as for instance at Bissex Hill, where a coarse conglomerate consisting of large blocks of cemented Chalky Mount grit and Murphys limestone separates Joes River mud-flows and Oceanic beds, sedimentation was apparently interrupted.

In the northern part of the Scotland district, where the Joes River beds are absent, the Oceanic formation overlies a deeply eroded surface built by the various subdivisions of the Scotland formation and overlaps the faults affecting the latter. Up to the present the writer has found in this area only one outcrop where the contact between Oceanic and Scotland formations is exposed. The following section could be observed at the base of the cliff south of Cherry Tree Hill (from bottom to top):

1. Gray, loamy clay with small lenses of fine sand (Scotland formation)
2. 2-3 millimeters brown limonitic loam with small gypsum crystals (old weathering surface?)
3. 15 centimeters silty calcareous mudstone (basal beds of Oceanics), immediately followed by white foraminiferal chalks—rich in *Hantkenina alabamensis*.

This section clearly shows that at the beginning of Oceanic time, previously emerging Barbados was very suddenly moved down into the region of deeper-water sedimentation, a fact well explained by Hess' hypothesis of downbuckling (Lit. 25).

The Oceanic beds are very much less folded and faulted than the Scotland beds and form large undulating anticlines and synclines. At the southern side of Bissex Hill, mud-flow veins intruding the Radiolarian earth were recognized by H. G. Kugler many years ago and in the Conset Bay district the Oceanic beds are considerably affected by mud-volcano activity.

#### AGE

Jukes-Browne and Harrison (Lit. 29b, p. 199) thought the Oceanic formation to be of Pliocene age, including in it the Bissex Hill marl, but in 1899, when the latter was separated from the true Oceanic beds, Franks and Harrison (Lit. 15) transferred the Oceanic formation into the Miocene. Trechmann in 1933 (Lit. 69, p. 41) was undecided whether the Oceanic formation had to be placed in the Pliocene or the Miocene, but in 1937 he seemed to favor the latter (Lit. 73, pp. 342 and 358). It was due to the progress obtained during the last twenty years in the study of small Foraminifera that the true age of the Oceanic formation was finally elucidated.

From samples collected by H. G. Kugler on the surface and from well-samples, H. Nägeli first recognized that the Oceanic formation has to be attributed to the upper Eocene, as its fauna shows striking resemblance to the one of the *Hantkenina* marls of the Hospital Hill of San Fernando (Lit. 34, p. 1444). The writer, after having made a preliminary examination of more than a hundred samples collected in the Mount Hillaby type section, completely agrees with this opinion. The easily recognizable index-fossil *Hantkenina alabamensis* Cushman is common from the base of the Oceanic formation (Bed No. 3) as high up as Bed No. 26. But also other species accompanying this fossil in the *Hantkenina* marls of Trinidad are present in Barbados and the coincidence is so perfect that H. Nägeli could state from a sample of a Barbadian test well that it "could almost be from the Hospital Hill of San Fernando" (private report, dated 15/4/36).

A similar Radiolaria-bearing facies of upper Eocene age is shown by the Principe formation of Cuba (Lit. 45), and it will be interesting to compare its fauna with the fauna of the Oceanic formation.

On the other hand, the fauna of the Codrington College marl, of which six samples have been examined up to the present, does not contain any further *Hantkenina*, but shows some resemblance to the lower Oligocene Guayaval marls of eastern Falcón (Venezuela).

TYPE OF SEDIMENTATION AND ORIGIN OF THE CLASTIC MATERIAL  
CONTAINED IN THE TUFF BEDS

Jukes-Browne and Harrison (Lit. 29b, p. 201), in comparing the Oceanic formation with the Radiolarian ooze, the Globigerina ooze and the red clays of modern oceanic depth, came to the conclusion that the basal Globigerina marls had been formed at a depth of 500–1,000 fathoms (914–1,828 meters), the Radiolarian earth at a depth of 2,000–3,000 fathoms (3,658–5,486 meters), the overlying foraminiferal beds at a depth of 1,000 fathoms (1,828 meters) and the red argillaceous earth at a depth of 2,000 fathoms (3,658 meters). Although the writer holds that Jukes-Browne and Harrison's arguments are not entirely conclusive and that new detailed studies on the Oceanic sediments would be highly desirable, he agrees in general to consider the Oceanic formation as a deep-sea deposit. This opinion is supported by the present topographic features of the area north of Barbados. H. Hess' new "Bathymetric Chart of the Caribbean Sea" (Lit. 82) clearly illustrates that the submarine ridge on which Barbados lies rises from the southeastern prolongation of the Brownson Trough, near latitude 17° North. This suggests that the Oceanic formation could be considered as a deposit of an upper Eocene pre-

decessor of the present Brownson Trough. This deposit was brought to the surface in Barbados as a consequence of the Oligocene, Miocene, and Pliocene folding movements. Hess (Lit. 25) has shown that the Barbados Ridge, as well as the Brownson Trough, lies more or less on the axis of the negative gravity-anomaly strip, and he assumes that at an earlier period this axis extended through northern Cuba, where again Radiolarian earth was deposited during the upper Eocene. Some samples of Cuban Radiolarian earth, which the writer has recently received through the courtesy of Mrs. Dorothy Palmer, show that—as sediments—the Cuban and Barbados Radiolarian earths are almost identical.

It seems therefore permissible to consider the Radiolarian earth of Barbados and Cuba as deposits of an upper Eocene predecessor of the present Brownson Trough. While on the wings, in Cuba and Barbados, the deposits of this upper Eocene deep-sea trough have been brought to the surface as a consequence of subsequent orogenic movements, in the central part deep-sea conditions continued to the present time. For checking this hypothesis it would be of the greatest interest to know if Radiolarian earth is actually deposited in the Brownson Trough. Unfortunately the writer could not find any information on this subject in the literature available to him in Barbados.

Concerning the occurrence of fine clastic tuff beds in the Oceanic formation, their volcanic nature has undoubtedly been proved by the studies of Miss Raisin (Lit. 29b, p. 180), who found them composed of small angular chips consisting mostly of feldspar many in broken crystals and numerous flakes and splinters of clear pumiceous glass, besides some rare mica and quartz. She also compared the Oceanic tuffs with the volcanic ashes which fell on Barbados in May, 1812, originating from the eruption of the Soufrière volcano of St. Vincent, and found them to be not unlike. The perfect agreement in the chemical composition between the volcanic ash which fell on Barbados in 1812 and the tuff beds of the Oceanic formation (Lit. 29b, p. 192) also suggests that the latter should be interpreted as falls of fine volcanic ashes or dust sunk through the water and mingled with the ooze which were accumulating on the sea floor. It may be remembered that such ash falls can sometimes be very important, as was proved in Barbados in 1902 and 1903 by the ashes originating from the eruptions of the Soufrière of St. Vincent (March 7-8, 1902, October 16-17, 1902, March 22, 1903). During the last eruption it was observed that the coarsest particles fell during the first hours. This corresponds well with the writer's observation that some of the ash beds of the Oceanic formation are coarsest at the base, becoming finer up-

wards and grading into the overlying siliceous marls and marlstones (for instance, the thin ash bed contained in Bed No. 13 of the Mount Hillaby type section).

In a very valuable paper on the Diatom- and Radiolaria-bearing upper Miocene deposits of western Algeria (Lit. 3), Anderson has shown the interesting relations which exist between these siliceous sediments and volcanism. He thinks that the silica used by the radiolarians and diatoms to build their skeleton has been furnished by ashes and fine dust expelled by neighboring volcanoes. In fact, volcanic ash beds are interstratified in the siliceous beds, not only of the Algerian, but also of the Californian Miocene; and in Barbados, where the common occurrence of volcanic tuff beds throughout the entire sequence of the Oceanic formation has been described, Anderson's hypothesis again seems to be confirmed.

Concerning the source of the volcanic ash contained in the Oceanic formation, it seems most natural to assume that it was lying where it lies to-day, that is, in the region occupied at present by the volcanic arc of the Lesser Antilles. In a later chapter we shall see that this opinion is confirmed by the nature of the Tertiary formations found on these islands.

#### AGE OF OCEANIC-SCOTLAND UNCONFORMITY AND COMPARISON WITH OTHER WEST INDIAN AND SOUTH AMERICAN COUNTRIES

Having determined the age of the Oceanic formation, one is now in a position to determine the age of the unconformity separating Scotland and Oceanic formations. The orogenesis causing this unconformity succeeded the deposition of the upper Scotland formation of middle Eocene age and preceded the deposition of the Oceanic formation of uppermost Eocene age. The orogenic movement therefore started at the middle-upper Eocene boundary and remained active during the entire lower part of upper Eocene time, as is suggested by the fact that two phases can be recognized—one preceding and one accompanying the extrusion of the Joes River mud-flows.

This orogenesis, which can be attributed to the "Pyrenean phase" of Stille's classification (Lit. 60), has a wide distribution throughout northwestern and northern South America and the West Indies.

In northwestern Peru its great importance has been recognized by Iddings and Olsson, who call the unconformity at the base of the upper Eocene one of the most important breaks in the entire Peruvian Tertiary section (Lit. 27, p. 16). The main phase of the orogenesis occurred here—as in Barbados—at the middle-upper Eocene boundary, preceding the deposition of the Talara formation, while a second-

ary phase took place within the upper Eocene, causing another unconformity between the Talara and the Saman formations, which are attributed respectively to the lower and upper part of the upper Eocene (Lit. 44, pp. 5-18).

In southwestern Ecuador also two phases can be recognized, the older one succeeding the middle Eocene Guayaquil limestone and the "Middle Grits," both of which contain several species of *Discocyclina* like the upper Scotland formation of Barbados (Lit. 57, p. 156). The younger phase precedes the upper Eocene Socorro formation, and the two unconformities enclose a peculiar deposit, the so-called "clay pebble beds" (Lit. 57, pp. 94-102).

In Panama an orogenesis within the upper Eocene is suggested by the fact that the Bucaru formation of early upper Eocene age is disconformably overlain by a limestone formation of uppermost Eocene age, to which belong the well known Orbitoid limestones of David and Haut-Chagres (Lit. 55, p. 590). A probable lateral facies of these is the Tranquilla shale which overlaps the andesitic basement in the upper Chagres Valley and contains a rich fauna of small Foraminifera (Lit. 9).

In Colombia—according to Butler (Lit. 7, p. 97)—a major unconformity preceded the deposition of the Toro formation, while small local unconformities mark its upper contact towards the Chorro formation.

In Venezuela, the orogenesis occurred within upper Eocene time, succeeding the deposition of the Mene Grande formation, which is conformable with the Pauji formation, the Misoa-Trujillo formation, and the entire Cretaceous system, and preceding the deposition of the Santa Rita conglomerate, which contains large pebbles of rocks derived from the older cycle (specially La Luna cherts, quartzites, various sandstones, white vein quartz and rare metamorphic rocks).

As a result of this orogenesis which the writer considers—besides the post-Miocene-pre-Pliocene one—the most important of all the Venezuelan Tertiary orogenic phases (Lit. 56, p. 66), a considerable land mass emerged in the region occupied to-day by the Cordillera de Mérida and the Cordillera de la Costa, separating the Orinoco sedimentary basin from the Zulia-Falcón sedimentary basin. During uppermost Eocene and lower Oligocene time the latter was partly occupied by a shallow sea, whose southern shore facies appears at the southern border of the Serrania de Aguanegra and can be followed from there towards Agualinda, Tacamire, and as far as the Cerro Campana in east Falcón. On the eastern side of the Maracaibo Lake this shore facies is suggested by the conglomerates and reefs of Cerro Venado.

The Zulía-Falcón basin itself was deformed during the upper Eocene orogenesis, as is seen from the fact that during uppermost Eocene and lower Oligocene time the sea occupied two narrow channels, separated by a ridge built up by highly folded Misoa-Trujillo sandstones and Pauji shales: in the southern channel the Aguanegra formation was deposited, comprising the uppermost Eocene Santa Rita conglomerate and the lower Oligocene Churuguara beds. In the northern basin the Tacal formation (Lit. 19) of uppermost Eocene and possibly lower Oligocene age was laid down.

The upper Eocene orogenesis also initiated the intrusion of basic igneous rocks in the Paraguaná uplift, causing special sedimentary conditions in this area during the Oligocene and Miocene epochs.

The erection of the Sierra de Perijá and the formation of the Maracaibo Basin also seems to date from these orogenic movements, since from the beginning of the Oligocene epoch, brackish-water sedimentation appeared in this area.

On the Curaçao-Bonaire Ridge, the orogenesis caused the unconformity between the Midden Curaçao formation and the Soebi Blanco conglomerate on one side, and the upper Eocene Seroe di Cueba and Seroe Montagne limestones on the other. Some dikes seem to have been intruded in Curaçao (Lit. 46, p. 1027).

The Orinoco Basin was equally deformed, as is clearly shown in Trinidad by the marked unconformity appearing at the base of the upper Eocene Mount Moriah formation.

The rôle which the upper Eocene orogenesis played in the area occupied to-day by the volcanic arc of the Lesser Antilles is described on pp. 1592-1602.

In the Greater Antilles, the presence of the upper Eocene orogenesis is indicated by the unconformity appearing in the base of the Bejucal formation in Cuba and by the unconformity separating older upper Eocene and middle Oligocene formations in Jamaica, Hispaniola, and Porto Rico (Lit. 75, p. 624).

#### THE BISSEX HILL MARL AND THE YOUNGER SEDIMENTARY FORMATIONS OF BARBADOS

Jukes-Browne and Harrison (Lit. 29b) included the Globigerina marls of Bissex Hill in the Oceanic formation, but in 1899 Franks and Harrison (Lit. 15) separated them from this formation. This is justified, as the two formations are quite different, not only lithologically but also in age, and are separated by an unconformity.

The bulk of the Bissex Hill marl consists of a yellow to orange-colored, coarse-grained, soft, somewhat sandy Globigerina marl with

common echinid remains, *Pentacrinus*, fish teeth and simple corals, including some lenses and inconstant ledges of fine algal and foraminiferal limestones. At the base there is a marked detrital bed containing pebbles and small lumps derived from the Oceanic formation.

The Globigerina marls of Bissex Hill have a very similar aspect to some foraminiferal tuffs which the writer saw in Martinique and Grande Terre, and actually, according to Miss Raisin, they contain a small quantity of broken feldspar crystals and volcanic glass (Lit. 29b, p. 173). They seem to be deposits of a moderately deep sea, in which volcanic dust was intermingled with the foraminiferal oozes.

The Bissex Hill marl has a thickness of approximately 15 meters and overlies unconformably a reduced thickness of Oceanic beds.

Besides the aforementioned fossils, the only determined macrofossils found in the Bissex Hill marl are *Archaeopneustes abruptus* Gregory and probably *Scaloria ehrenbergi* Schomburg, but as these fossils are not known elsewhere, they can not be used for an age determination.

Chapman (Lit. 15) recognized 120 species of Foraminifera in the Bissex Hill marl and stated that Miocene and Pliocene species (especially the former) are strongly in evidence. In 1936 H. Nägeli came to the conclusion that the Bissex Hill marl must be upper Oligocene, somehow intermediate between the upper Marl and the St. Croix formation of Trinidad (private report, dated 15/4/36). The writer agrees with this age determination, finding the foram fauna similar to that of the A<sub>3</sub>-A<sub>4</sub> and the A<sub>3</sub> zone of the Aguasalada clays of east Falcón (Venezuela), which are placed in the uppermost Oligocene and the lowermost Miocene (Lit. 56).

Therefore it seems that between the Oceanic formation of upper Eocene-lower Oligocene age and the Bissex Hill marl of uppermost Oligocene or lower Miocene age an important part of the strata is missing in Barbados, but owing to the very limited occurrence of the Bissex Hill marl, it is extremely difficult to form an idea on the events occurring in Barbados during the second half of the Oligocene epoch.

Even less is known of the Miocene history of Barbados, deposits of this epoch not having been recognized as yet on this island. It is possible that of the 3,000 feet of foraminiferal marls encountered in a well in southern Barbados, a part might belong to the Miocene, but this is only a supposition, as samples from this extremely interesting well have unfortunately not been kept (Lit. 41).

The next younger deposit is the Coral rock, of Pleistocene and partly Pliocene age, according to Trechmann (Lit. 73). This limestone formation overlies the Oceanic formation unconformably and in some

places rests directly on the Scotland formation, proving that an important period of erosion preceded its deposition.

It is not intended to give a description of this formation, as that would be outside the scope of this paper.

#### THE ARC OF THE LESSER ANTILLES

(Compare Figs. 2, 3 and 4)

While the history of the younger Tertiary is very imperfectly known in Barbados, not yet allowing a comparison with the neighboring countries, some particularities of its Eocene sedimentation furnish us with a key to the problem concerning the origin of the volcanic arc of the Lesser Antilles.

It has been seen that the lower-middle Eocene Scotland formation is an entirely detrital deposit mostly deriving from metamorphic rocks, while in the overlying upper Eocene-lower Oligocene Oceanic formation volcanic ash beds are common throughout the formation, proving that volcanic activity had been started on the volcanic arc of the Lesser Antilles. It has also been shown that a strong orogenesis took place between the deposition of the two formations, causing the extrusion of important mud-flows.

Therefore, it seems permissible to ask whether the orogenic forces which initiated the mud-volcano activity in Barbados were also responsible for the first appearance of volcanic eruptions in the arc of the Lesser Antilles.

The conditions on these islands seem to confirm this hypothesis.

The Tertiary sediments on all the islands from Carriacou in the south to St. Barthélémy in the north, consist of an enormous thickness of stratified volcanic tuffs and agglomerates, deposited in a shallow, but rapidly subsiding sea. The tuffs themselves are in some places fossiliferous, and at various horizons there are fossil-bearing limestones interstratified in the tuff formation, permitting the determination of its age.

The oldest part of this tuff formation is exposed on St. Barthélémy, where it overlies unconformably the syenite porphyry of Gustavia. Interstratified in the great thickness of tuffs there are three prominent limestones.

The lower one—of a thickness of 45 meters—forms the promontory between Anse des Lézards and Anse des Cayes and includes two zones of cross-bedded conglomeratic tuffs.

The middle limestone—32 meters thick—crops out at the promontory separating Anse des Cayes and Baie de St. Jean and the upper

limestone forms the top of the mountain immediately east of the bifurcation of the mule track going from Gustavia to Anse des Lézards and to Colombier.

While the upper limestone consists of dense, flaggy limestones, almost barren of fossils, the two lower limestones contain corals, echinids, mollusks, and an abundant fauna of larger Foraminifera described by Cushman (Lit. 10).

*Dictyoconus americanus* Cushman  
*Nummulites antilleus* Cushman  
*Nummulites parvulus* Cushman  
*Discocyclina (Discocyclina) marginata* Cushman  
*Discocyclina (Asterocyclina) antillea* Cushman  
*Lepidocyclina antillea* Cushman

The formation has been called St. Bartholomew limestone, but the writer would prefer the term St. Bartholomew formation, as the limestone occurs only as intercalations in the great thickness of volcanic tuffs and agglomerates. Cleve, in 1871 (Lit. 8, p. 26), correlated the St. Bartholomew formation with the middle Eocene of Europe (Calcaire grossier, Bracklesham beds) and stated the relationship with the San Fernando beds of Trinidad (= Mount Moriah formation). Later on Vaughan (Lit. 74, 75, 76) and Cushman (Lit. 10, p. 24) transferred it into the upper Eocene, comparing its coral fauna with the one of the Priabonian of northern Italy. As a consequence the St. Bartholomew formation has been regarded for many years as the type of the West Indian upper Eocene, but recently Vaughan (Lit. 77, p. 97) expressed some doubts about the correctness of his former opinion and stated that the formation might be middle instead of upper Eocene. Vaughan's doubt is based on the presence of *Dictyoconus* and of *Lepidocyclina antillea* Cushman, which closely resembles *L. gardnerae* Cole from the middle Eocene of Texas. Besides the fact that the identity of the two species of *Lepidocyclina* has not yet been proved, the writer wishes to mention that *Dictyoconus* was also found by Gorter and Van der Vlerk (Lit. 20, p. 98, sample No. 2b and Lit. 56, p. 58) in the Mene Grande beds of Rio San Pedro (Venezuela), in the material originally described by Tobler (Lit. 66). On the other hand, the presence of *Lepidocyclina* in the St. Bartholomew limestone indicates this formation to be younger than the upper Scotland formation of Barbados, in which this genus seems to be entirely absent. For the present the writer therefore considers the St. Bartholomew formation to belong to the lower part of the upper Eocene.

To the lower Oligocene the tuffs of Fonds Moustique (Lit. 4) in Martinique belong, as well as the thick tuff formation building up the Central Plain of Antigua. Both formations are characterized by the

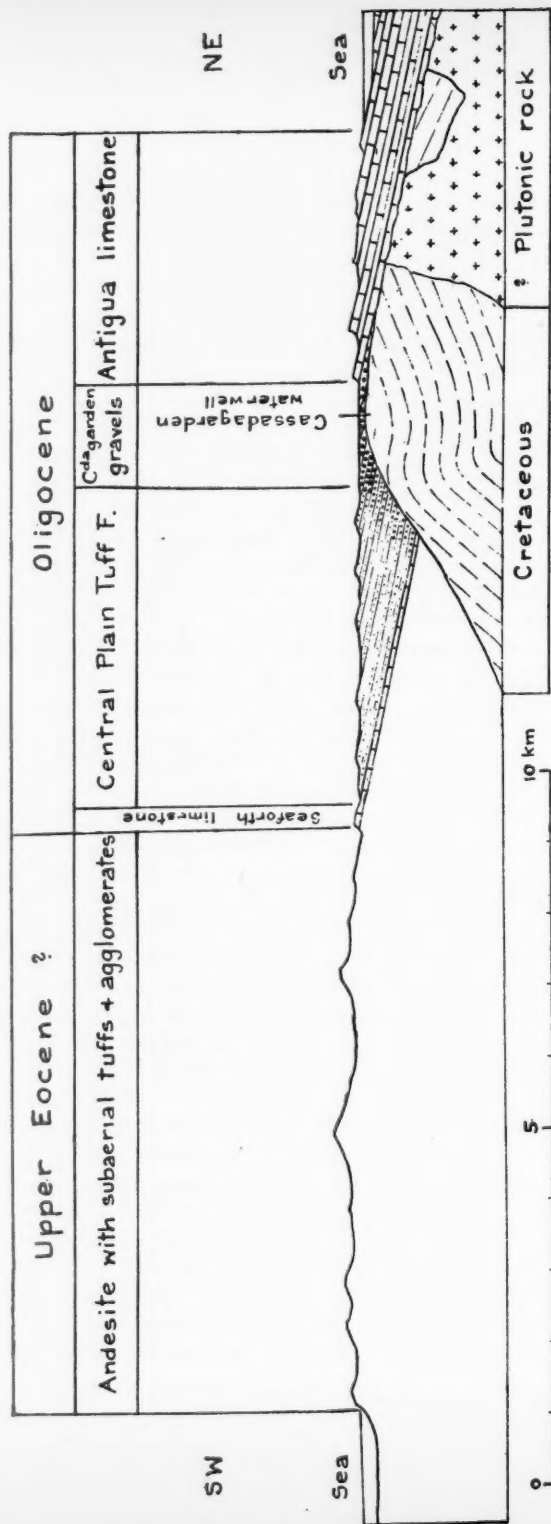


FIG. 2.—Hypothetical cross section through island of Antigua, showing position of Cassadagarden water well.

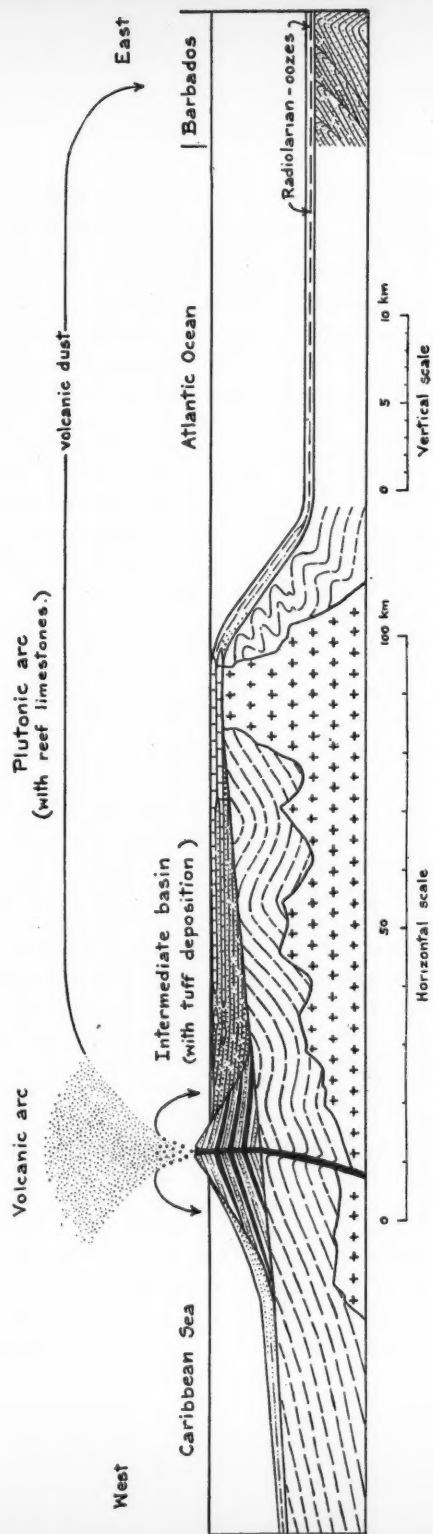


FIG. 3.—Hypothetical cross section through arc of Lesser Antilles, showing conditions of sedimentation during Oligocene epoch.

occurrence of fossil wood and are overlain by limestones of middle Oligocene age. The Central Plain tuff formation of Antigua includes at Snapper Point a lenticular mass of limestone rich in large *Lepidocyclina* (Lit. 12) and other beds of the same formation furnished a fauna of fresh-water gastropods from cherts (Lit. 6). Rutten's supposition (Lit. 51, p. 1049) that a part of the Antigua tuffs might be Cretaceous must be denied since large *Lepidocyclinas* have now also been found by the writer in the Seaforth limestone, which forms the base of the Central Plain tuff formation (see Fig. 2). According to Earle (Lit. 12) this formation clearly overlies the andesites and associated subaerial agglomerates and ash beds forming the southwestern part of the island, and there seems to be a transition between the stratified, water-deposited tuffs and the subaerial tuffs and agglomerates. The andesites have therefore to be considered as still belonging to the lower Oligocene, or more probably to the upper Eocene.

Middle Oligocene, characterized by large *Lepidocyclinas*, and upper Oligocene, characterized by small *Lepidocyclinas*, are known from several islands. In Carriacou (Lit. 40) Lehner has found near the base of his "Lower Tuff Series" some lenses of reef-limestone, rich in large and small *Lepidocyclinas*, while lenses of limestone containing only small *Lepidocyclinas* occur towards the top of the same formation. In southeastern Martinique the middle and upper Oligocene limestones already form important masses, but are still separated by a considerable thickness of intermediate tuffs: the upper limestone, known as the Macabou limestone, contains layers very rich in small *Lepidocyclinas*, which were discovered long ago by Giraud (Lit. 18). In the lower limestone for which the term "Bourg du Marin limestone" is proposed here (thickness 85 meters), a typical fauna of large and small *Lepidocyclinas* has only recently been discovered by the writer. In Antigua finally the limestones with large *Lepidocyclinas* and those with small *Lepidocyclinas* are united in a singular thick limestone formation: the Antigua formation.

The distribution of the facies during middle and upper Oligocene with an increase of reef limestone towards the east and an increase of volcanic tuff material towards the west, clearly shows that the volcanoes furnishing the tuff material were lying in the west somewhere close to the actual volcanoes of the Antillean arc (see Fig. 3).

Uppermost Oligocene (Aquitanian) is represented by the Anguilla limestone of Anguilla, the Carriacou limestone of Carriacou, and possibly by the Morne Vent limestone of Martinique, which latter forms a lenticular mass within the thick tuff formation known as the Vaclun tuffs. All these limestones contain the last and rare small *Lepidocyclinas*.

Lower Miocene is present in Carriacou where the Carriacou limestone is conformably overlain by the Grand Bay tuffs. They contain a rich mollusk fauna described by Trechmann (Lit. 72), and are correlated by this author with the Thomonde formation of Haiti, which is regarded as Burdigalian by Woodring. To the same stage the fossiliferous tuffs and the limestone of Grande Terre seem to belong (Lit. 5).

The youngest dated beds in the Tertiary tuff formation of the Lesser Antilles are the Bassignac tuffs of Martinique, which—on the basis of their rich mollusk fauna—have been correlated by Cossman with the Gatun formation of Panama, and therefore seem to be of middle Miocene age (Lit. 18, p. 15).

All the different beds of the Tertiary tuff formation of the Lesser Antilles seem to be conformable and transitional among themselves, an erosional unconformity only being reported from Anguilla, where the Anguilla limestone lies on a peneplaned surface of basic igneous rocks (Lit. 76). On all the islands the Tertiary tuff formation is only gently folded and shows a similar structural style to the partly contemporaneous Oceanic formation of Barbados. The deformation of the Tertiary tuff formation seems to be due to the post-Miocene-pre-Pliocene orogenesis, which, as well as the upper Eocene phase, the writer considers the most important orogenic phase in Venezuela. It is possible that these movements gave a new impulse to the volcanism, which persisted into the present time.

Returning to the question placed at the beginning of this chapter (p. 1592), whether the orogenic forces which initiated the mud-volcano activity in Barbados were also responsible for the first appearance of volcanic eruptions on the arc of the Lesser Antilles, it is evident from the summary given that this possibility is entirely affirmed: not only does the tuffaceous facies of the Tertiary sediments prove the first appearance of volcanism in upper Eocene time and its persistence up to the present, but the unconformity found at the base of the St. Bartholomew formation also shows that an orogenesis has preceded the deposition of the Tertiary tuff formation.

It can therefore be concluded that the erection of the volcanic arc of the Lesser Antilles is due to the important phase of orogenic movements occurring during upper Eocene time and known as the Pyrenean phase (Lit. 60).

Is this phase entirely responsible for the building up of this island arc, or does there exist an older foundation?

We have seen already that on the Curaçao Ridge, as well as in the Greater Antilles, an orogenesis occurring near the Cretaceous-Eocene boundary has caused the intrusion of important masses of plutonic

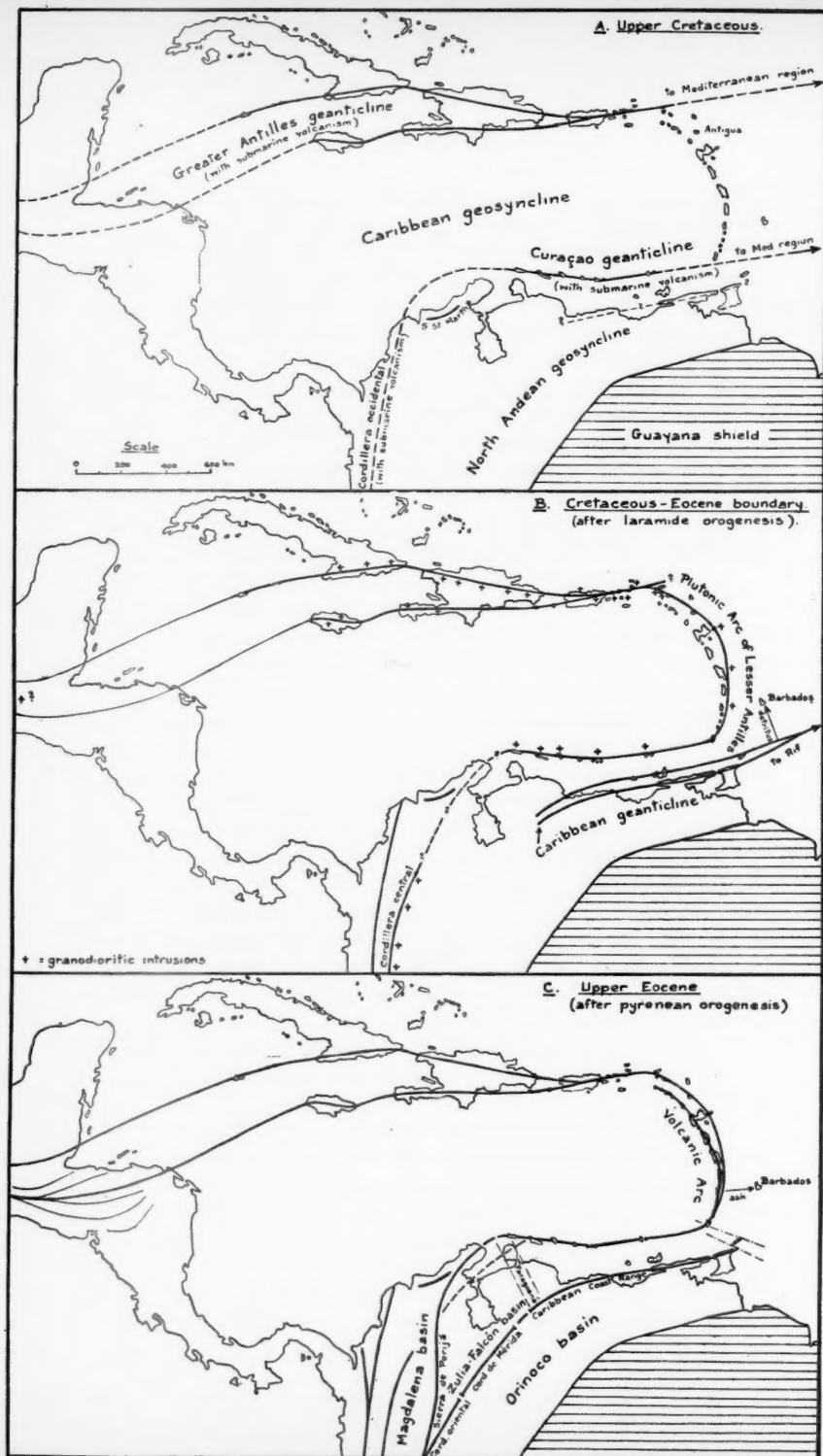


FIG. 4.—Development of orographic elements in Antillean-Caribbean region during Upper Cretaceous and Eocene epochs.

rocks, such as quartz diorites and granodiorites (see Fig. 4B). From Porto Rico these plutonites can be followed into the Virgin Islands, and on the opposite side of the Anegada passage they appear also on the so-called limestone Caribbees, in St. Martin as quartz diorite (Lit. 42), in St. Barthélémy as syenite porphyry (Lit. 8) and in Désirade as granodiorite (Lit. 5). South of this latter island no outcrops of plutonites are known, but their presence in the underground of the volcanic islands is proved by the occurrence of similar rocks as blocks in the Tertiary tuffs and the ejections of the actual volcanoes.

The continuation of this zone of young granodioritic rocks is found in the Venezuelan islands, which, as shown already, form a part of the Curaçao Ridge.

Therefore, it seems that the orogenesis occurring at the Cretaceous-Eocene boundary and known as the "Laramide phase" has caused the erection of a mountain chain in the Lesser Antilles fused in the north with the axis of the Greater Antilles, in the south with the Curaçao Ridge; but whereas in these two areas the mountain chain was emerging above sea level, exposing their rocks to denudation, in the sector of the Lesser Antilles only a submarine ridge seems to have been built, causing the ascendance of the plutonic magma. In the northern part, this older plutonic ridge was lying northeast of the younger volcanic ridge, and its axis seems to be marked by the outcrops of the plutonic rocks in St. Martin, St. Barthélémy and Désirade. During the upper Eocene orogenesis this older ridge was folded up again, denuded and finally buried under the reefs deposited along its crest and the volcanic debris ejected by the volcanoes of the inner arc.

Our knowledge of the Cretaceous history of the Lesser Antilles is entirely based on the occurrence of Upper Cretaceous chalk in Antigua, which is the only place where Cretaceous has been proved paleontologically. It is therefore of the greatest importance to know under what circumstances this Cretaceous comes close to the surface and enters into relationship with the neighboring formations. The writer is gratefully indebted to W. R. Forrest for showing him the locality in Antigua, and owes some supplementary information to C. T. Trechmann and H. H. Hess, who visited the place after him (compare Fig. 2).

The Cretaceous chalk was encountered when an old water well, situated on the Golf and Race Course at Cassadagarden, was deepened in 1930. At the well site, there still exists a good outcrop of cross-bedded, brown sandy tuffs with conglomeratic layers containing pebbles of volcanic rocks. These beds belong to the "Cassadagarden

Gravels," which represent a conglomeratic facies intercalated in the upper part of the Central Plain tuff formation and which are covered by the Antigua limestone (Lit. 12). At the Cassadagarden well these conglomeratic tuffs dip slightly to the northeast and at a distance of approximately 400-500 meters to the northeast are normally overlain by the *Lepidocyclina*-bearing limestones and chalky marls of the Antigua formation.

The following is an extract from a report kindly furnished by W. R. Forrest.

The original well was 6 feet in diameter and 25 feet deep. During the drought of 1930 the well ran dry and it was decided to deepen it. At the bottom of the well there was a considerable amount of debris, viz: skeletons of dogs, some quaint ancient stumpy dark glass bottles, with short neck and bulging body, laterally compressed, capacity about 20 to 24 ounces. The surface of the glass was partly encrusted with lime and the glass had become opaque, evidently from long immersion in water. This indicates that the well never extended previously below the 25' level.

The excavation of the new well was commenced below this level with the same diameter of 6 feet by two men with fork and shovel. After passing through 17 feet of grit similar to the upper beds, the chalk bed was reached 42 feet below the surface. The rock consists of a very white, fine-grained, friable chalk containing numerous fragments of flint. The chalk-bed was 4' 6" thick, and showed vertical cracks, which facilitated its removal in blocks of various sizes. Two large estate cattle carts were loaded with these blocks of chalk. Underneath the chalk a very hard dark rock was encountered, which had to be worked with a drill. After penetrating 6' 6" of this hard rock, of which unfortunately no sample had been kept, the inflow of brackish water stopped further operations at a total depth of 53'.

The foraminiferal fauna of the Antigua chalk has been described by Cushman (Lit. 11), who found the fauna to be an equivalent of portions of the Taylor marl of Texas and of the Craie Blanche (Senonian) of the Paris Basin. Nearly all the species determined by Cushman from the Antigua chalk have been described from the White chalk of the Paris Basin or from similar formations of central Europe.

How is the occurrence of the Antigua chalk to be interpreted?

The possibility has first to be mentioned that this rock could be chalk from England or France, which, according to information received from H. Rose in Barbados, has commonly been used in older West Indian water wells for purifying purposes. It would therefore be highly desirable to check this possibility by digging another well near by. The writer, on the information furnished by W. R. Forrest, however, is rather inclined for the present to believe the Antigua chalk "in place." In this case, the lithological contrast between the chalk and the overlying conglomeratic tuffs is so sharp as to make it im-

possible to believe the former an intercalation in the latter. Rutten's assumption (Lit. 51, p. 1049) that a part of the basal volcanic deposits of Antigua has to be considered as Cretaceous can therefore not be admitted.

It is the writer's opinion that the Cretaceous chalk of Antigua belongs to the older plutonic arc of the Lesser Antilles, which was built up by the Laramide and Pyrenean orogenic phases and later was buried by the volcanic debris of the younger volcanic arc. This is quite understandable if it is realized that Antigua lies approximately on a straight line between Désirade and St. Barthélémy, where the plutonic rocks of the older arc appear at the surface to-day. The existence of this ridge in the underground of Antigua would also give an explanation for the "Cassadagarden Gravels" and for the reefs of the overlying Antigua formation, which could be considered as a near-shore facies along a ridge built up by Cretaceous sediments and plutonic rocks intruded during the Laramide orogenesis (see Fig. 2). In this connection Hess' finding of a granitic pebble in the Cassadagarden gravels near the water well is of great importance (private information) and Earle's statement (Lit. 12) that an unconformity can be observed in Willoughby Bay between the Antigua formation and the Cassadagarden gravels would agree well with the hypothesis of a repeatedly moving geanticlinal ridge.

The Antigua chalk seems to have been formed in quiet deeper waters, and its facies is in sharp contrast to the one of the upper Cretaceous of the Curaçao Ridge and the Greater Antilles where it is largely of volcanic origin. This volcanic facies of the Cretaceous still seems to be present near the northern end of the older Antillean arc, in St. Martin, where the Pointe Blanche formation consists of a well stratified and strongly metamorphosed alternation of fine-grained ashes, coarse tuff-breccias containing fragments of effusive rocks and somewhat crystalline limestones (Lit. 42). The Pointe Blanche formation overlies the quartz diorite, but is intruded and metamorphosed by the latter and is therefore older, that is, probably Cretaceous. It seems that during the Cretaceous, St. Martin either belonged to the chain of the Greater Antilles, St. Croix and the Virgin Islands, or received its volcanic material from this near-by axis.

It may finally be concluded that—in contrast to the Curaçao Ridge and the Greater Antilles—no orogenic movements accompanied by submarine volcanism occurred in the central part of the Lesser Antilles during the Upper Cretaceous, but this region was covered by a fairly deep and quiet sea directly connected with the Mediterranean (see Fig. 4A). Only in the north (St. Martin) was volcanic material

received from the neighboring axis of the Greater Antilles and the Virgin Islands.

SUMMARY OF GEOLOGICAL HISTORY OF THE  
ANTILLEAN-CARIBBEAN REGION

During the Lower Cretaceous, a geosynclinal basin was formed in the region occupied to-day by the Venezuelan Andes, limited in the south by the old Guayana Shield (see Fig. 4A). By a continuous deepening of the basin, the neritic, clastic, and calcareous sedimentation of the Lower Cretaceous epoch (Tomon and Cogollo formations) was succeeded during the Upper Cretaceous epoch by calcareous and clayey sedimentation of the bathyal type (La Luna and Colon formations). Towards the close of the Cretaceous a geanticlinal ridge seems to have emerged in the region occupied at present by the Caribbean Coast Range, as is suggested by the clastic facies of the uppermost Cretaceous of the Rio Querecual section (Lit. 23). On the other hand, in the area occupied now by the Cordillera de Mérida, only a little fine clastic material appears in the mainly clayey sediments (Mito Juan formation). The fauna of this Cretaceous sedimentary basin is so similar to the one of the Mediterranean Sea that a communication must have existed between these two regions (Lit. 16, p. 5).

In the north this basin was limited by the Curaçao axis, which during the Upper Cretaceous epoch showed a different kind of sedimentation with large intermixture of volcanic material (ashes and lavas). It must be assumed that in this region a warping of the sea floor caused the opening of fissures, along which the basic magmas could ascend, giving rise to an important submarine volcanic activity. Similar conditions must have occurred in the western Cordilleras of Colombia, where basic lavas of considerable thickness have been extruded (Lit. 16, p. 6). After the deposition of the lower Senonian, the warping movement was accentuated, leading to the emergence of the Curaçao Ridge and possibly to the first granodioritic intrusion. During the upper Senonian the Curaçao Ridge shows neritic sedimentation, with conglomerates and rudistid- coral- and orbitoid-bearing limestones (Seroe Teintje limestone and Rincon formation).

In the northern part of the Caribbean Sea, the Greater Antilles showed during the Upper Cretaceous epoch a very similar development to the Curaçao Ridge, with the same volcanic facies and a possible emergence preceding the deposition of the neritic, rudistid-orbitoid-bearing sediments of the upper Senonian (for instance, Blue Mountain formation of Jamaica).

The axis of the Greater Antilles and the Curaçao Ridge, which

show typical geanticlinal features during the uppermost Cretaceous, have an approximate west-east, that is, a Mediterranean strike and it is probable that by these ridges a connection between the West Indian and the Mediterranean region was established, along which a migration of the fauna could take place. On the other hand, a connection between the Greater Antilles and the Curaçao geanticlines through the Lesser Antilles seems not to have existed during the Upper Cretaceous epoch, as is indicated by the entirely different facies of the Antigua chalk.<sup>13</sup> This sediment suggests a quiet and fairly deep sea in this region during the Upper Cretaceous epoch (see Fig. 4A).

At the Cretaceous-Eocene boundary (see Fig. 4B) a more important orogenic movement occurred on the geanticlines of the Greater Antilles and the Curaçao Ridge (Laramide orogenesis). Both have been largely intruded by a granodioritic magma and have emerged, suffering large denudation during the lower and part of the middle Eocene. The detritus originating from the denudation of the Curaçao Ridge is found in the Midden Curaçao formation and the Soebi Blanco conglomerate, that from the Greater Antilles Ridge in the Richmond formation and the base conglomerate of the Plaisance limestone.

A connection was established between the Greater Antilles and the Curaçao Ridge by the upfolding of an arc in the Lesser Antilles, largely intruded by a granodioritic magma. This first foundation of the Antillean arc consisted probably of a submarine ridge, as no detrital deposits originating from it can be detected.

Whereas in the Venezuelan geosyncline marine sedimentation was mostly continuous at the Cretaceous-Eocene boundary, in the area occupied to-day by the Caribbean Coast Range and the Northern Range of Trinidad the Laramide orogenesis caused the definite emergence of a geanticlinal ridge. The upfolding was accompanied by intrusions of a granitic magma and vein-quartz injections which, together with the contemporaneous dynamo-metamorphism, caused an alteration of the Mesozoic sediments. During lower and middle Eocene, the Caribbean Ridge seems to have formed a low but continuously rising island festoon, furnishing the clastic material for an important Flysch formation deposited along its northern slope and known as the Misoa-Trujillo formation of northwestern Venezuela and the Scotland formation of Barbados. The Pointe-à-Pierre formation of central Trinidad may represent a similar Flysch facies developed along the southern foot of the Northern Range. Another positive movement of the Caribbean Ridge at the beginning of the

<sup>13</sup> Provided the Antigua chalk is in place (see p. 1600).

middle Eocene is reflected in the sedimentation of Barbados by the appearance of a coarse clastic facies in the upper Scotland formation (Chalky Mount grits). The fact that the thickness of these grits increases in Barbados in a southeasterly direction suggests that the Caribbean Ridge passed south of Barbados, and as nothing can be found in the Lesser and Greater Antilles which could be the continuation of this ridge, it may be assumed that it was connected with the Mediterranean mountain system, especially with North Africa. In the Rif Mountains of Morocco and their eastern prolongation, the Kabylia chain of Algeria, an orogenesis occurred at the Cretaceous-Eocene boundary, causing a temporary emergence of this mountain chain and Flysch deposition during the following Eocene epoch. The Caribbean Range forms the northern border of the South American continent as the Kabylia-Rif chain forms the extreme north front of the African continent. South of this chain (southern Morocco and southern Algeria), as in southern Trinidad, sedimentation was not interrupted at the Cretaceous-Eocene boundary. The existence of a ridge connecting North Africa with northern South America in lower and middle Eocene time would give an explanation for the presence of identical species of shallow-water mollusks in both countries (Lit. 48, pp. 202-204).

The orogenic movements previously dealt with have to be considered as precursory movements, precluding the first paroxysm which was reached during upper Eocene time (Pyrenean phase).

This orogenesis was not confined to a few geanticlinal ridges, but was of a more regional nature. Not only have the larger mountain chains been folded up, but the whole area occupied by the former north Andean geosyncline has been affected by the movements, as is suggested by the regional unconformity appearing at the base of or within the upper Eocene: in northwestern Venezuela this unconformity is found at the base of the Aguanegra and Tacal formations, in eastern Venezuela at the base of the Merecure formation (?), in Trinidad at the base of the Mount Moriah formation, in Barbados at the base of the Oceanic formation, in Curaçao and Bonaire at the base of the Seroe de Cueba and Seroe Montagne limestones and on the Antillean arc at the base of the St. Bartholomew formation.

The major events caused by the Pyrenean orogenesis are as follows (see Fig. 4C).

The Cordillera de Mérida and the Caribbean Coast Range completely emerged, forming a large terrestrial barrier between the Orinoco basin on the south and the Zulia-Falcón basin on the north. The latter was limited to the west by the emerging Sierra de Perijá, in the

north by the re-elevated Curaçao Ridge, to which the Sierra de Perijá was welded. The Zulia-Falcón basin was deformed and divided into secondary basins and ridges, thus offering very complicated depositional conditions in the succeeding Oligocene epoch (including uppermost Eocene). The most important event within the Zulia-Falcón basin was the individualization of the NNW-SSE directed Paraguaná uplift, due to the intrusion of basic igneous rocks. During the Oligocene and Miocene epochs this area formed a separation between the sedimentary basins of western and eastern Falcón. A slight volcanic activity was also shown on the Curaçao Ridge, where dikes cutting through Midden Curaçao beds have been observed (Lit. 78 and 46).

In Barbados the orogenesis caused great disturbances accompanied by the extrusion of important mud-flows, and Trinidad as a whole was also strongly deformed.

In the Lesser Antilles the formerly built submarine plutonic arc was elevated above sea level and denuded, and on its inner convex side a new island arc originated, consisting of a rosary of volcanoes, the volcanic arc of the Lesser Antilles (see Fig. 3). Volcanic activity continued here from upper Eocene to the present time, supplying sedimentation with an enormous amount of ash material which filled the sea depression existing between the volcanic and the older plutonic ridge and buried the latter. Thus an enormous thickness of volcanic tuffs has been deposited in the neighboring sea, comprising the whole sequence from upper Eocene to middle Miocene at least. The finer volcanic dust was carried as far as Barbados, where it was intermingled with the foraminiferal and radiolarian oozes deposited here in a fairly deep sea.

Whereas the erection of the volcanic arc of the Lesser Antilles is clearly reflected in the upper Eocene and Oligocene sediments of Barbados, there are no further signs of the existence of the Caribbean geanticline which furnished Barbados with abundant clastic material during lower and middle Eocene. It must be assumed that during the upper Eocene revolution the latter ridge broke down and the connection with North Africa was interrupted (see Fig. 4C). This hypothesis could explain the difference between the West Indian and Mediterranean faunas, which became more and more pronounced during the succeeding epochs. Whereas a connection between the West Indian and the Mediterranean provinces undoubtedly existed during the Cretaceous and the older Eocene, it is probable that later these regions became separated by the building up of the Antillean arc with its convex side directed towards the east and the Rifian arc with its convex side directed towards the west. It seems that the latter arc was

formed as a consequence of the repeated orogenic movements which affected the Rif-Kabylian chain during the upper Eocene and the Oligocene epoch.

It is not intended here to deal with the history of the Antillean-Caribbean region during the later Tertiary, which must be based on a detailed analysis of the facies in the sedimentary basins of Venezuela and Trinidad. Several smaller movements occurred there during the Oligocene and Miocene epochs leading to the second paroxysm at the Miocene-Pliocene boundary (Rhodanic phase, Lit. 60). In Barbados the precursory movements might be represented by the unconformity separating Bissex Hill marl and Oceanic formation, while the Rhodanic orogenesis probably created the upfolding of a new ridge, the Barbados Ridge, which was highly denuded before the deposition of Coral rock in uppermost Pliocene or Pleistocene time. The upfolding and fracturing of Barbados in post-Pleistocene time shows that the movements on the Barbados Ridge are still continuing.

The Rhodanic orogenesis also seems to have caused a renewed elevation of the volcanic arc of the Lesser Antilles and a rejuvenation of its volcanic activity. This is suggested by the fact that the tuff material of the post-Miocene volcanic cycle, deposited on the Caribbean islands, is of a subaerial nature and overlies unconformably the folded water-deposited and stratified tuffs of the Oligo-Miocene cycle.

Concerning the problem of the Antillean arc, the writer's opinion, expressed in this paper, is intermediate between the conception of Ed. Suess (Lit. 61) and L. Rutten (Lit. 51) on one side and the conception of Hill, Gregory, and R. Staub on the other (Lit. 51 and 59).

During the Upper Cretaceous epoch communication between the Antillean and the Mediterranean region seems to have existed along certain geanticlinal ridges, such as the Greater Antilles and the Curaçao Ridge (Fig. 4A). The Laramide orogenesis seems to have created a connection between the Caribbean Ridge and the Rif-Kabylian Ridge, persisting during lower and middle Eocene time. By the same orogenesis a first connection between the Greater Antilles and the Curaçao Ridge was established by a submarine plutonic arc in the Lesser Antilles (Fig. 4B). The Pyrenean orogenesis caused the emergence of this older arc and created a new volcanic arc on its inner side, the volcanic arc of the Lesser Antilles. By these events South and North America were connected in upper Eocene time through the Antillean arc (Fig. 4C). On the other hand the Pyrenean revolution seems to have interrupted the communications previously existing between the Antillean and the Mediterranean region, which latter was closed towards the west by the creation of the Rifan arc.

The relations between the Antillean and the Mediterranean region have been only roughly sketched in the present paper. Much more stratigraphical and paleontological detail work is necessary in both regions before a more accurate account of these interesting relations can be attempted. However, the views expressed here are in perfect agreement with the recent article of Rutsch (Lit. 49), according to which the differentiation of the mollusk fauna of the Mediterranean and the Caribbean region began in upper Eocene time.

A remark may be added on the magmatic cycle of the Antilles, which confirms the law established by Kossmat (Lit. 32, pp. 398-402): the first phase of an orogenic cycle is characterized by submarine extrusions of basic lavas of the ophiolitic type (Cretaceous of the Curaçao Ridge and the Greater Antilles), whereas during the second phase large masses of acid plutonic rocks are intruded (granodioritic rocks of the Curaçao Ridge, the Lesser and the Greater Antilles, produced at the Cretaceous-Eocene boundary). Owing to the fact that the *mise en place* of the plutonites has consolidated and stiffened the underground, in the third phase the eruptions take place along fissures (volcanic eruptions on the Curaçao Ridge during upper Eocene and on the volcanic arc of the Lesser Antilles from upper Eocene into Recent time). Van Tongeren, in comparing analyses of igneous rocks from the three magmatic phases and various points of the Curaçao Ridge and the Lesser Antilles, states that "notwithstanding the large distance and the great difference in geological age, the conformity of the chemical properties is striking" (Lit. 67, p. 163), thus proving the strongly homogeneous character of this magmatic province.

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## JURASSIC-CRETACEOUS (GIRÓN) BEDS IN COLOMBIA AND VENEZUELA<sup>1</sup>

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### ABSTRACT

This note covering an extensive region in Colombia and Venezuela has for its purpose the establishment of the identity of the Upper Jurassic Girón in the two countries. This opinion is based mainly on wide acquaintance with the Girón in Venezuela and a more general study of it in Colombia. However, in the writer's opinion, it may be subject to modification by new observations and new paleontologic evidence.

Since Hettner (1892) described and introduced the Girón formation in the stratigraphy of Colombia (named after his type locality near the town of Girón approximately 11 kilometers south of Bucaramanga, Santander), there has existed a widespread confusion in the definition, limits, and stratigraphic position of the formation. Hettner attributed to his Girón a Cretaceous age, without however having found fossil evidence in his type locality. As a result the Girón of Hettner covers strata of different formations and ages.

The conception of the Girón beds as a stratigraphic unit has since been extended over large areas of northern and eastern Colombia, and southern as well as western Venezuela. However, in Venezuela, the same Girón beds were originally called by Sievers (1888) "Conglomerado de Lagunillas," which included only the lower part of Hettner's Girón. The age of the Venezuelan Girón was much disputed and Liddle placed his "Old Red series" somewhere between the Devonian and the Jurassic. L. Kehrler (1937) considered his Girón of Lower Cretaceous age.

The writer (1937) referred to the same formation in the Venezuelan Andes, as the "Red formation" and from stratigraphic position, as well as correlation, deduced its age as being Upper Jurassic or lowermost Cretaceous.

Recently, several geologists of the Shell Petroleum Corporation, L. Kehrler (1938), and Kundig (1938), described fossils from the Girón beds at the locality of La Quinta near La Grita (Táchira) in Venezuela. These consist of fish remains, fish scales, and coprolites, all of which were determined by A. Smith Woodward as belonging to the ganoid genus *Lepidolus*, common in the Jurassic of Europe and also

<sup>1</sup> Manuscript received, February 12, 1940.

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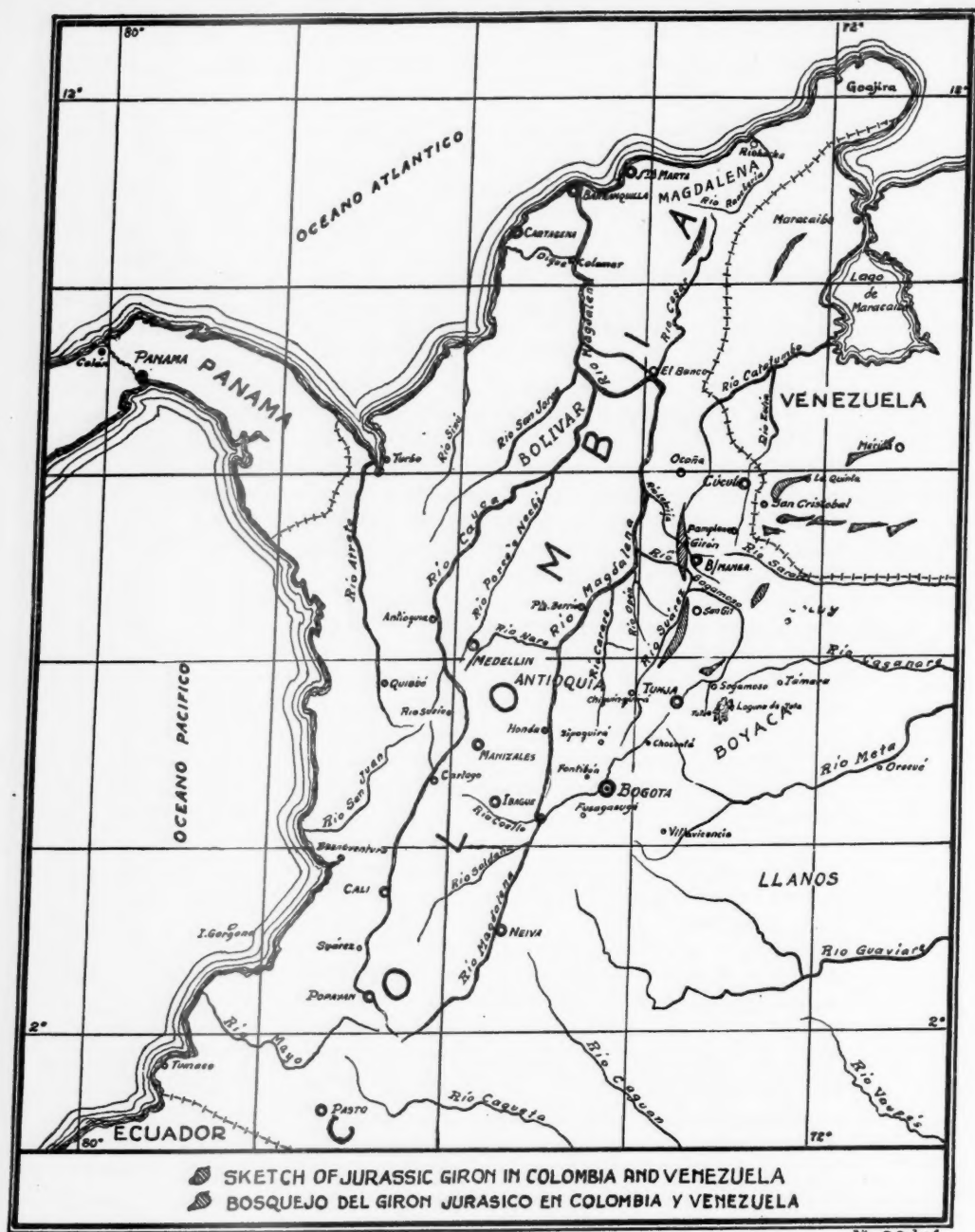


FIG. 1.—Map of part of Colombia and Venezuela showing location of Jurassic Girón formation.

occurring in the Lower Cretaceous of Brazil. Woodward, however, favors an Upper Jurassic age of these ganoid remains.

Due to this discovery the designation of the La Quinta formation after the type locality was officially accepted to replace the terms "Girón," "Lagunillas conglomerate," or "Old Red series," in Venezuela. Thus, it seems that the debated question of the age of the Girón beds in Venezuela, can be resolved as Jurassic, possibly Upper Jurassic.

TABLE I  
GENERAL CORRELATION CHART OF CRETACEOUS-JURASSIC BEDS  
IN COLOMBIA AND VENEZUELA.

	VENEZUELA	COLOMBIA			
	State of Táchira	Monte de Santander (Barco Concession)	Cordillera Oriental	Middle Magdalena Valley (after A. K. McGill)	
UPPER CRETACEOUS	Mto. Juan ±(300 m) Colon Shale ±(600 m)	Ro. de Oro Shale ±(15-190 m) Mto. Juan Shale ±(350-420 m) Colon Shale ±(250-450 m)	Guadalupe Beds ±(1000 m)	Umu Beds	
				Palma Limestone	
MIDDLE CRETACEOUS	La Luna ±(50 m) Cogollo Series ±(350 m)	La Luna Limestone ±(50-90 m) Cogollo ±(180-400 m)	Upper Villeta ±(1500 m)	Tablazo Shale	
			Lower Villeta	Tablazo Limestone	
LOWER CRETACEOUS	Tomon Series ±(800 m)	Uribeño Beds ±(500-550 m)	Cocuy Series ±(2500 m)	Pay Shale	
				Santa Rosa Limestone	
LOCAL UNCONFORMITY					
UPPER JURASSIC	La Quinta Series (Girón) ±(3000 m)			Girón Beds ±(500 m)	
UNCONFORMITY (Hiatus)					
CAMBRIAN TO ALGONQUIAN	Metamorphic formations (Phyllites, micaschists, granites, etc.)				

In Venezuela the Jurassic La Quinta formation occurs not only in the states of Táchira and Mérida but also in the Sierra de Perijá Mountains west of the Maracaibo basin.

The La Quinta formation (Girón) in the Venezuelan Andes consists of red massive conglomerates at the base. These are interbedded with red sandstones and dark red clay shales. The conglomerates are irregular and vary in size from small pebbles to boulders the size of a fist and larger. They consist either of quartz or, east of Mérida, granite and metamorphic rocks. In the upper part the sandstones acquire a clearer color and in eastern Táchira (according to the writer's observations) grade into yellowish white sandstones of the overlying Lower Cretaceous beds which belong to the Tomon series.

The conformable contact of the two formations, with their gradual passage from one into the other, was observed by the writer in several localities in Táchira and is also confirmed by similar observations made by Hedberg in the Perijá range. However, Kundig mentions a hiatus between the La Quinta (Girón) and the overlying Tomon series. If such an unconformity exists it is undoubtedly local.



FIG. 2.—Girón beds on road from Girón to Lebrija (Santander).

The maximum thickness of the La Quinta (Girón) series in Venezuela is about 3,000 meters; however, it varies greatly from one place to another. The occurrence of malachite and azurite is in places characteristic of this formation in Venezuela.

The overlying Tomon series is a succession of white to gray, quartzitic (in places micaceous) sandstones, interbedded with blackish gray clay shales, some of which are carbonaceous. Both the sandstone beds and the shale bear plant remains and coaly plant impressions. The lowest part of the series is commonly interbedded with fossiliferous limestone. In the state of Táchira the thickness of the series is about 800 meters.

While the La Quinta formation (Girón) generally overlies progressively the metamorphic basement rocks over great areas (except

where it lies in contact with the lower Paleozoic), the conformable Tomon series transgresses the basement only in the areas north of Táchira, where the La Quinta (Girón) is missing, through erosion or non-deposition.

In Colombia the two formations, that is, the equivalent of the La Quinta formation and the equivalent of the Tomon series, were for a



FIG. 3.—Sandstone beds of Cocuy series forming high ridges of Nevado de Cocuy (elevation, approximately 5,200 meters). Faulted escarpment faces east toward the llanos.

long time associated under the term Girón beds, as originally used by Hettner.

However, Grosse as early as 1930 observed the striking difference in the lithologic character of the formations composing the original Girón of Hettner, and in the Gámbita Mountains region separated the upper part of the formation, which he called the "White sandstone beds," from the lower, true Girón beds. Also Notestein (Schuchert, 1935) noted the apparent confusion in the nomenclature of the two different formations.

Notestein observed an unconformity near Los Santos, between the true redbeds of Girón and the overlying series of white to gray sand-

stones. It seems probable, however, that the unconformity is local, and in general the formations form a transitional contact.

E. A. Scheibe (1938) admits that the Girón of Hettner includes several formations and proposes to subdivide it into upper and lower Girón, without, however, definitely separating the two formations.

Scheibe, in his general geological map of the Cordillera Oriental of Colombia, includes in the Girón beds also the Cocuy quartzite of



FIG. 4.—Girón beds at contact with Cocuy series sandstones near La Mesa (elevation, approximately 3,300 meters) on road to Bucaramanga.

Hettner. Now, the formation forming the escarpment ranges and Nevado de Cocuy represents a great thickness of white to grayish yellow, coarse to medium-grained sandstones, interbedded with gray to black beds of clay shales, which are in places carbonaceous. The shale and the sandstones bear plant remains and impressions, which the writer observed in a large area on the Nevado de Cocuy, and here designates as the Cocuy series.

East of the Páramo de Chita and at the foot of the eastern escarpment, above the Salina de Chita, R. Scheibe in 1922 found plant remains, which according to Th. Lipps were determined as: *Weichselia* cf. *peruviana* (Neumann) Zeiller and *Brachyphyllum* sp. cf. *Pompeckiji*

Salf. Thus the age of the Cocuy series seems to be determined as Neocomian. The same sandstone beds of Cocuy were observed by the writer in wide areas in the Cordillera Oriental, varying locally in texture and color. They extend over many high páramos, for example, Almorzadero, Mogorontoque, and Santurban. The resistant sandstone beds form typical and conspicuous escarpments.

The Cocuy series may well be associated with the "White sand-



FIG. 5.—Limestone beds of lower part of Cocuy series near La Mesa. Limestone is richly fossiliferous.

stone beds" of Grosse, and represent the upper (Cretaceous) part of Hettner's Girón.

The thickness of the Cocuy series exceeds 2,500 meters; however in other localities of the wide area of its occurrence it seems to be considerably thinner.

In 1937 the writer had the opportunity of studying the geology of the state of Táchira in Venezuela in some detail. A reconnaissance through the Cordillera Oriental of Colombia permitted him to follow the stratigraphic development of the formations in question in the two countries.

Besides the type locality, near Girón, the true red Girón beds are well exposed at La Mesa, on the descent from Páramo Santurban to Bucaramanga, at an elevation of approximately 3,280 meters. In this area the contact with the limestone beds of the overlying Cocuy series seems to be unconformable.

The true Girón beds can also be observed on the road from Bucaramanga to Tunja in the valley of Rio Chicamocha, overlying the metamorphic basement at elevations of about 2,700 meters. The overlying Cocuy series is typically developed in the valley of Rio Suárez on the road to Ciba. The Girón also appears underlying the Cocuy sandstone series at Sogamoso and on the road to Cúcuta, the first outcrops occurring near Chitagá.

*Conclusion.*—It appears that the Girón of Hettner covers two different formations, for the following reasons.

1. The true Girón, consisting of red, conglomeratic sandstones and clay shales, transgressing over the metamorphic basement, is apparently of Jurassic age, because these beds represent the southerly continuation of the paleontologically identified La Quinta formation across the Colombian border.

2. It underlies a well developed and very widely distributed series of sandstones (gray-yellow to white, with some limestone beds at the base)—the Cocuy series of Lower Cretaceous age.

The Cocuy series can be followed rather definitely from east of Bogotá (Cáqueza region) along the Cordillera Oriental to the Venezuelan border, where it corresponds with the Venezuelan equivalent—the Tomon series, or Uribante beds of Sievers.

In the Rio Negro-Cáqueza region in Colombia, the same sequence of the Cocuy series appears as the Cáqueza series, and was erroneously described by W. Kehrler (1936), as the Girón beds of the Bogotá-Vilavicencio section.

Thus the fossils described by Karsten (1886), such as the ammonites, *Crioceras duvalii* Lev. var. *undulata*, and others, clearly indicate the Lower Cretaceous (Lower Neocomian) age of the Cáqueza series, corresponding with the same age of the Cocuy series on the north, along the Cordillera Oriental.

In conclusion, a paleogeographic sketch of northwestern South America in Jurassic time shows that it is now possible to extend the marine Jurassic sedimentation from Peru (its northernmost known extent until recently) across extensive areas in Colombia and Venezuela and as far as Trinidad. According to recent information furnished by A. G. Hutchison (1938) an Upper Jurassic ammonite fauna of *Idoceras* C. Burckhardt was found near Puerto España, Trinidad.

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## PALEOZOIC LIMESTONE OF TURNER VALLEY, ALBERTA, CANADA<sup>1</sup>

W. D. C. MACKENZIE<sup>2</sup>

Turner Valley, Alberta

### ABSTRACT

Paleozoic limestone and dolomite of Mississippian age, ascribed to the Rundle formation (probable Madison equivalent of Montana) is the chief oil and gas formation in Turner Valley, Alberta. Production is obtained in two main porous producing zones which are found within the first 450-460 feet of the Paleozoic.

The producing zones are dolomites separated by a dense hard zone with considerable chert. The porosity determinations vary from 1 to 20 per cent. Variations of porosity and permeability, presence or absence of secondary calcite in the porous zones, and fractures make the determination of reserves on the basis of the volumetric method inadvisable. Chemical analyses of the producing zones are given and the results of acid treatments are discussed. Electrical logging is still in the experimental stage.

### INTRODUCTION

Practically all the gas and oil production in the Turner Valley field of Alberta comes from the Paleozoic limestone. It is a well known fact that reservoir studies of many limestone fields are complicated by the wide variations of porosity and permeability; and Turner Valley is no exception. A thorough analysis of all available geologic data pertaining to the producing formations should guide engineers when attempting to make estimates on reserves and similar problems. During the past 2 years the writer has made a detailed study of the producing Paleozoic limestone of Turner Valley in an attempt to compile some data that might be of assistance in geologic correlation and production engineering practice.

### GENERAL STRUCTURAL GEOLOGY

The reader is referred to papers by George S. Hume,<sup>3</sup> Theodore A. Link and P. D. Moore<sup>4</sup> and A. J. Goodman<sup>5</sup> for excellent contributions

<sup>1</sup> Published by permission of Royalite Oil Company, Limited. Manuscript received, January 18, 1940.

<sup>2</sup> Petroleum engineer, Royalite Oil Company, Limited.

<sup>3</sup> George S. Hume, "Oil and Gas in Western Canada," *Geol. Survey Canada*, Econ. Geol. Ser. 5 (2nd ed.).

———, "Turner Valley, Alberta," *Geol. Survey Canada Paper* 38-7 (1938).

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<sup>4</sup> Theodore A. Link and P. D. Moore, "Structure of Turner Valley Gas and Oil Field, Alberta," *Bull. Amer. Assoc. Petrol. Geol.*, Vol 18, No. 11 (November, 1934).

<sup>5</sup> A. J. Goodman, "Notes on the Petroleum Geology of Western Canada," *Jour. Inst. Petrol. Tech.*, Vol. 21, No. 138 (1935).

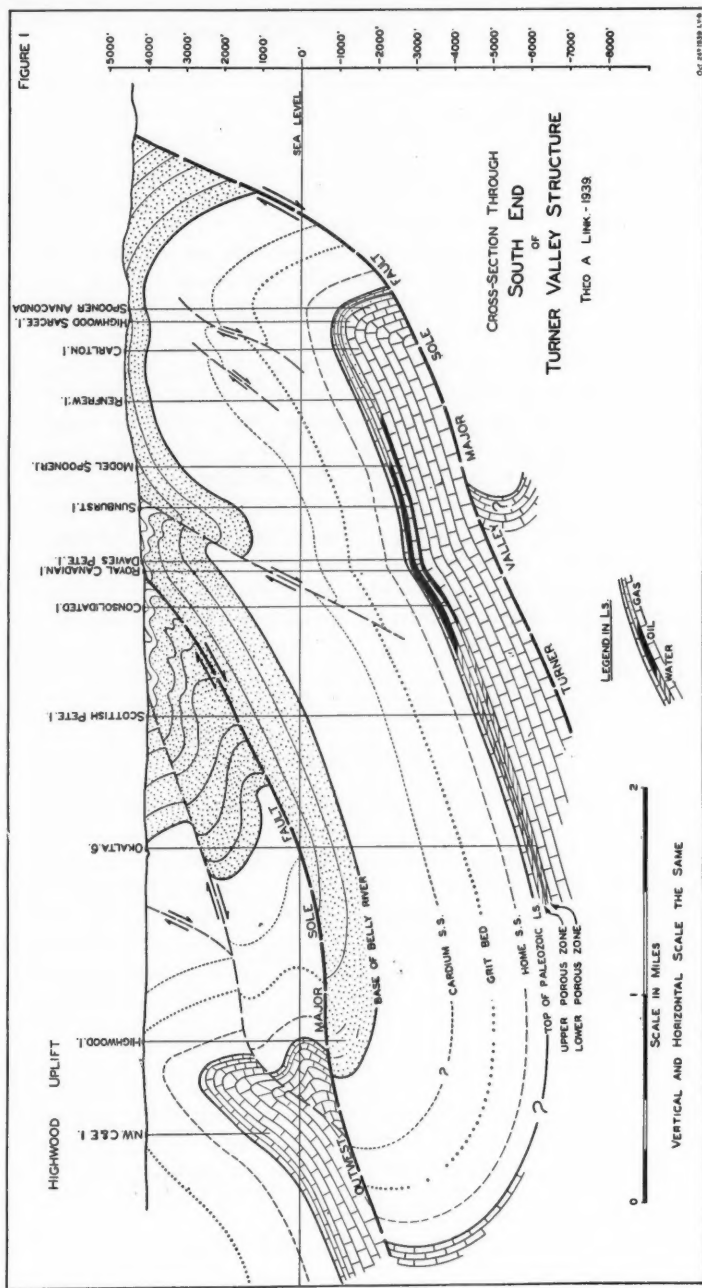


FIG. 1

on the structural geology and general stratigraphy of Turner Valley. To discuss the orogenic history of the structure would be outside the scope of this paper and would be mere repetition of the previous contributions. However, some generalizations on the structural geology of this field are necessary before the productive formations can be discussed, because of their interrelationship.

Figure 1 is a typical section taken normal to the strike. The structure is shown as an anticline on the upthrown side of a major sole fault. This thrust sheet, developed by the Rocky Mountain uplift, is one of the most easterly of the Foothills belt. One mile east of the structure the west limb of the Alberta syncline has a regional dip of about  $5^{\circ}$ E. The steep dip of the east flank of the Turner Valley anticline is probably due to drag folding when displacement of the thrust sheet took place. Hume<sup>6</sup> regards the faulting as being "the major structural feature and the whole structure as being a drag fold above it due to eastward thrusting . . . some preliminary folding took place but the faulting rather than the folding is the important feature." Link and Moore,<sup>7</sup> in a comprehensive discussion of the Foothills orogenies as applied to Turner Valley, bring out this same principle. The compressive forces from the west caused a great number of minor faults and folds in the relatively incompetent Cretaceous and Jurassic beds, but they did not deform the Paleozoic limestone to the same extent, because of its competency.

#### GENERAL STRATIGRAPHY

For the purposes of this paper the abridged geologic column in Table I should be sufficient to give the reader a general idea of the stratigraphic section. The now established subsurface stratigraphy of all pre-Montana strata in Turner Valley is almost wholly the work of P. D. Moore and J. G. Spratt. However, in the last 3 years, many wells have penetrated as much as 3,500 feet of Montana sediments before encountering the Colorado (or Benton). Correlation of these younger and more difficult sediments is being done jointly by all geologists active in the field.

#### PALEOZOIC LIMESTONE

The Paleozoic limestone in Turner Valley is commonly referred to as the "Madison lime" and is the approximate equivalent of the Madison in Montana. In southern Alberta the Paleozoic is well exposed in

<sup>6</sup> George S. Hume, personal correspondence (1939).

<sup>7</sup> Theodore A. Link and P. D. Moore, *op. cit.*, p. 1438.

PALEOZOIC LIMESTONE OF TURNER VALLEY 1623

the Banff area and studies of this area by Dowling,<sup>8</sup> Shimer,<sup>9</sup> Warren,<sup>10</sup> and Allan<sup>11</sup> have resulted in a type section. The Turner Valley Paleozoic limestone is correlated with the Rundle formation of the Banff section. Recent work by Warren<sup>12</sup> indicates that the Rundle is Mississippian.

TABLE I  
ABRIDGED GEOLOGIC COLUMN  
TURNER VALLEY GAS AND OIL FIELD

Age	Series	Formation	Normal Thickness (feet)	Lithologic Character
Upper Cretaceous	Montana	Edmonton	?	Non-marine; coal, coaly shales, sandstones, shales, and sandy shales
		Bearpaw	200 ±	Marine; near shore; sandy shales
		Belly River	1,600	Non-marine; coaly shales, sandstones, shales, and sandy shales
	Colorado	Alberta shales (Benton)	2,500	Marine; shale, a few sandstones near top and base
		Blairmore	1,100	Non-marine; lower part may be semi-marine; coaly shales, sandstones, shales, and limy sandstones near base
Lower Cretaceous		Kootenay	100	Coal and coaly shales
Jurassic		Fernie	250	Marine, sandstone at top, shales and limestone bands
Paleozoic		Rundle or Madison	1,200	Limestone

Link and Moore<sup>13</sup> state that the two probable sources of the oil produced from the Paleozoic are the Fernie (Jurassic) shales and the upper sections of the Paleozoic limestone. Goodman<sup>14</sup> also postulates a Paleozoic origin for most of the hydrocarbons. This theory is now

<sup>8</sup> D. B. Dowling, *Geol. Survey of Canada Pub.* 949 (1907).

<sup>9</sup> H. W. Shimer, *Geol. Survey of Canada Sum. Rept.* (1910); *Bull. Geol. Soc. America*, Vol. 24 (1913), pp. 233-40, 112-13. *Geol. Survey of Canada Bull.* 42 (1926), pp. 1-84.

<sup>10</sup> P. S. Warren, *Geol. Survey of Canada Mem.* 153 (1927).

<sup>11</sup> J. A. Allan, *Geol. Survey of Canada Sum. Repts.* (1912-1914-1915); also Guide Book No. 8, Pt. 11.

<sup>12</sup> P. S. Warren, "The Limestones of the Rocky Mountains in Canada" (unpublished manuscript).

<sup>13</sup> Link and Moore, *op. cit.*, p. 1437.

<sup>14</sup> A. J. Goodman, *op. cit.*, p. 250.





generally accepted although at the time that Goodman, Link, and Moore published there seemed to be some opposition to this view.

The problem of migration of the hydrocarbons has caused considerable speculation; theories on time and distance of migration depend on each individual interpretation of the orogenic history. In the writer's opinion the migration of the hydrocarbons did not take place either laterally or vertically for any great distance.

#### CORRELATION OF PRINCIPAL LIMESTONE ZONES

In Figure 2 the field is divided into five areas and on it a type log of the limestone constructed for each area. The logs of all wells that have penetrated the Paleozoic limestone in Turner Valley were carefully studied before preparing the data used in Figure 2. The upper section of the type log for areas *D* and *E* may be open to some criticism. Most of the wells drilled in areas *D* and *E* were completed prior to 1932 and a number are known to have deviated considerably from vertical. As very few of these wells have been directionally surveyed, the limestone dips may be incorrect.

In Figure 2 the five type logs have been correlated in the profile. This profile reveals at least one important fact: the thickness of the upper porous zone is relatively uniform, but the lower porous zone is *absent* in area *D* and is only 5-10 feet in thickness in the south part of area *A*. Since the upper porous zone and the lower porous zone are the main producers, their extent is important. Those who wish to calculate the total void space for reserve estimates should consider the variations in the thickness of the lower zone.

#### PETROGRAPHY OF LIMESTONE

##### NOMENCLATURE

It is unfortunate that the limestone zones were not better named than "Upper porous," "Middle hard," "Lower porous," *et cetera*, as, although locally descriptive, they are sometimes confusing. These names have been generally accepted, and in some cases written into Government regulations, so that changes are now not possible. It is hoped that reference to Figure 2 will clarify any of the later statements that may involve difficulties with local names.

*Porous zones.*—In all Paleozoic samples from Turner Valley, porosity is everywhere associated with dolomitization. With the petrographic microscope it is commonly impossible to differentiate between dolomite and calcite crystals. Therefore, to make a positive identification of the dolomitic zones, chemical analyses of certain samples were made. All the limestone cuttings from Davies Petroleum No. 2

FIGURE 3.

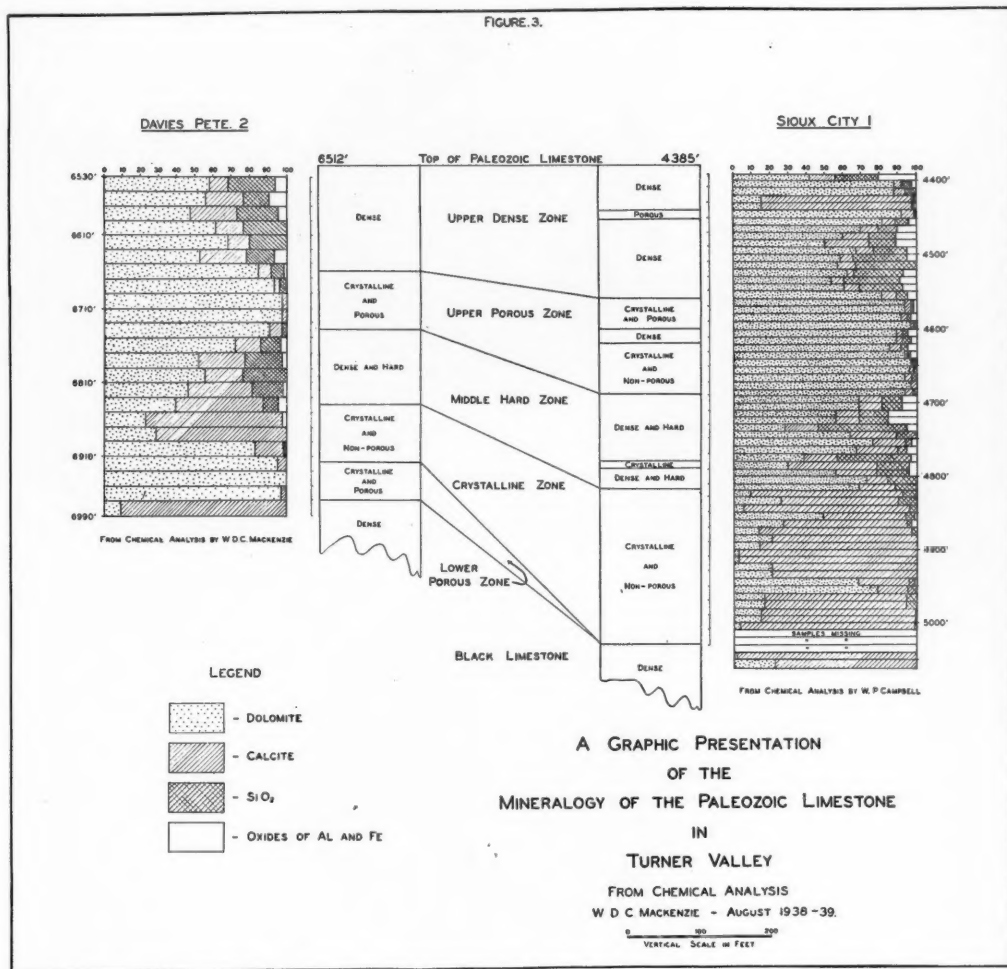


FIG. 3



FIG. 4.—60 mag., X-nicols, Sterling Pacific No. 6, lower porous zone, 7,050 feet.

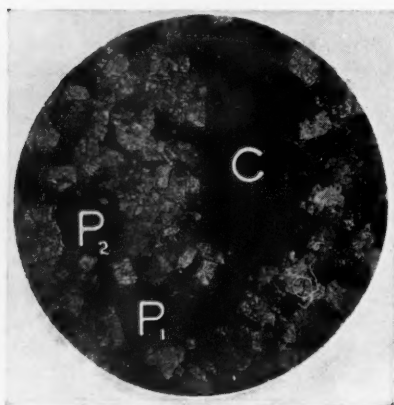


FIG. 5.—60 mag., X-nicols, West Turner No. 1, lower porous zone, 7,240 feet.

(area *A*, Sec. 21, T. 18, R. 2 W., 5th) were analyzed quantitatively for calcium, magnesium, and silica. Campbell<sup>15</sup> made a similar analysis of the Sioux City No. 1 (area *E*, Sec. 1, T. 20, R. 3 W., 5th) limestone samples and then showed graphically the percentage of dolomite. The results from the Davies Petroleum No. 2 and Sioux City No. 1<sup>16</sup> determinations are shown in Figure 3. In this graph, values of *Ca* and *Mg* were computed to  $\text{CaCO}_3$  and  $\text{CaMg}(\text{CO}_3)_2$  by merely assuming all the *Mg* to have originated from dolomite. It should be quite evident that the porous zones are almost pure dolomite.

Figures 4 and 5 are typical thin sections of fragments from the porous zones. The characteristic feature of these sections and all others made from porous chips is the crystalline appearance. In core specimens the voids are relatively small; a very few might be  $\frac{1}{4}$  inch in diameter but the great majority are less than  $\frac{1}{16}$  inch. In areas *D* and *E* of Figure 2 the porous zones are commonly brown in color but almost everywhere in areas *A*, *B*, and *C* their color is white.

On Figure 5 the marked areas *P*<sub>1</sub> and *P*<sub>2</sub> are voids and *C* indicates calcite crystals. In certain thin sections it was observed that calcite crystals occurred at or near the boundaries of the voids. Lemberg's<sup>17</sup> solution was used to identify these calcite crystals before final preparation of the thin section. With polarized light these calcite crystals would invariably have "mutual extinction"; hence, it seems probable that in certain parts of the porous zones secondary calcite has been precipitated. Goodman<sup>18</sup> also observed calcite crystals having "mutual extinction" in some of his sections of porous chips from Sioux City No. 1 and stated that the porosity had been reduced by the precipitation of these secondary calcite crystals. A large number of thin sections from the porous zones have been examined. In some cases possible secondary calcite crystals were observed but in many other sections they were absent. Where observed the crystals have undoubtedly reduced the porosity, but the reduction in permeability as compared with the pure porous dolomite is of great importance. The limits of drainage of

<sup>15</sup> W. P. Campbell, "Variations in the Chemical Composition of the Oil and Gas Bearing Limestone at the Sioux City Well, Turner Valley, Alberta," *Trans. Canadian Inst. Min. Met.*, Vol. 40.

<sup>16</sup> Only Campbell's analysis for the upper 670 feet of limestone is shown in Figure 3.

<sup>17</sup> Lemberg's solution—preparation described in W. H. Twenhofel, *Treatise on Sedimentation*, 2nd ed., p. 331: "prepared by boiling for 20 minutes a mixture of 4 grams  $\text{AlCl}_3$ , 6 grams extract of logwood and 60 grams of water, with constant stirring and replacement of water lost by evaporation." The mixture is cooled and filtered. Dilutions between 1:20 and 1:40 seem to give the best results.

<sup>18</sup> A. J. Goodman, *op. cit.*, pp. 231-34.

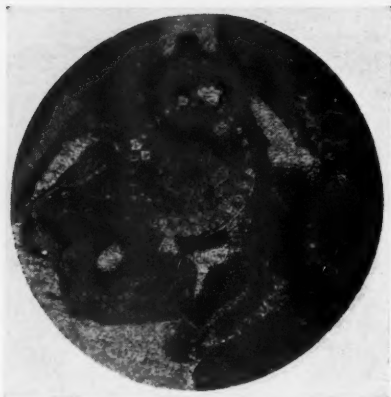


FIG. 6.—60 mag., X-nicols, Richland No. 2, crystalline zone, 6,710 feet.

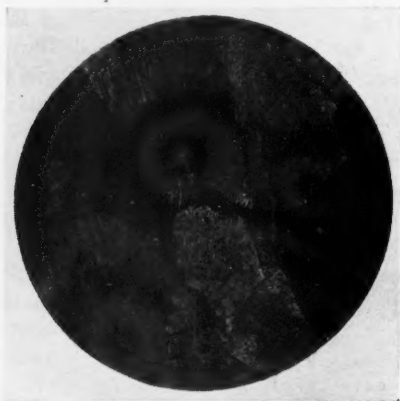


FIG. 7.—60 mag., X-nicols, Advance No. 5A, crystalline zone, 6,355 feet.

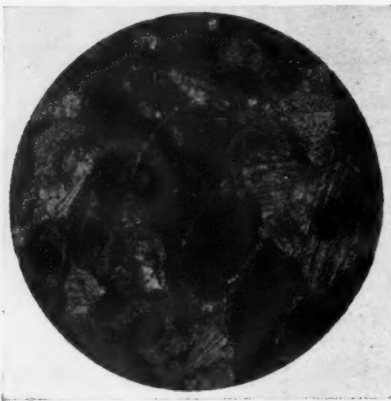


FIG. 8.—60 mag., X-nicols, Royalite No. 17, crystalline zone, 3,905 feet.

a bore hole could well be dependent on the extent of zones in which reprecipitation has taken place.

*Crystalline zone.*—Figures 6, 7, and 8 are representative of the crystalline zone as encountered in areas *A*, *C*, *D*, and *E* of Figure 2. As the name implies, the drill cuttings are crystalline in appearance, and they are invariably soft and almost pure white in color. Although Figures 6, 7, and 8 appear dark, this was done purposely with polarized light in an attempt to bring out the detail as satisfactory photographs of these sections were difficult to make. All thin sections examined, drill cuttings, and core specimens, show no porosity. In one well at the extreme south part of area *A* of Figure 2 the crystalline zone extended from the base of the middle hard zone to the black limestone, and drilling was completed after a few feet of black limestone had been penetrated. Shortly after the well was brought into production it was acidized with a packer set in the middle hard zone. In the hope that the geological log was in error the crystalline zone was acidized but in spite of high pump pressures no fluid would penetrate the crystalline zone. Abundant microfossils as in Figures 6 and 8 are often found in sections of the crystalline zone.

Referring again to Figure 3 it is evident that the crystalline zone is principally calcitic. The writer at one time held the opinion that the crystalline zone was once part of the lower porous zone and was later rendered non-porous by precipitation of secondary calcite in the voids of the dolomite. This theory was discarded for two principal reasons as follows.

1. It would be expected that at least some voids would be observed which are not completely filled by secondary calcite, yet no such evidence has ever been obtained.
2. If the crystalline zone was once a porous dolomite the percentage of dolomite in this zone should be much greater than shown by chemical analysis.

The writer therefore considers the crystalline zone as being a section of the limestone that has never been dolomitized. The relationship between the crystalline zone and the lower porous zone is an interesting problem in sedimentation. In Figure 2 the formations below the middle hard zone are either porous and dolomitic, or non-porous and calcitic, or distinct combinations of both. One possible theory is suggested and is dependent on the assumption that leaching and replacement are processes necessary in the formation of dolomite. If certain areas were dolomitized soon after, or contemporaneous with sedimentation, then waters high in calcium carbonate would be present in areas adjacent to the dolomitized "islands." Consequently

highly talcitic limestones would be formed around the dolomitized areas. Small volumes of the leaching waters may have remained in the porous dolomite and as a result some reprecipitation of calcite took place in the voids of the dolomite (C in Fig. 5).

*Middle hard zone and upper dense zone.*—The most persistent marker in the limestone is the middle hard zone. Throughout the field it is a dark, non-porous, dense, and siliceous limestone. Two or three bands of pure chert, about 1–2 feet in thickness, are everywhere encountered in the middle hard zone. As many as 20 rock bits have been required to drill this extremely hard 60-foot zone. In thin sections of

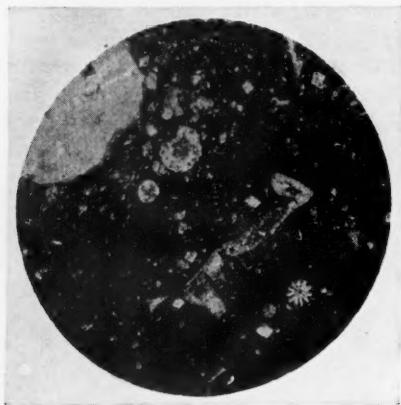


FIG. 9.—60 mag., ordinary light, Dalhousie No. 8, black limestone, 6,900 feet.

cuttings from this zone the crystal boundaries could not be observed at magnifications of less than 150X.

The upper dense zone and the middle hard zone are similar. In the upper dense zone most of the limestone is dense and non-porous, with some sections being also extremely hard. In color the upper dense zone is dark gray to buff. One thin chert band is ordinarily encountered about 20 feet above the base of this zone. Although the first hundred feet of the Paleozoic drilled is called the "Upper dense," there are porous parts in this zone. In all areas of Figure 2 a porous band is shown about 10 feet below the Jurassic-Paleozoic contact. This thin porous band is dolomitic but has not yielded commercial production and is in many places cemented off because the oil string is usually set 10–20 feet in the Paleozoic. In areas D and E (Fig. 2) an irregular porous zone is shown 60 feet below the top of the limestone and, in two

or three wells, this porous zone has been the main producer.

*Black limestone.*—Figure 9 is an example of a typical chip from near the top of the black limestone. Drilling is usually stopped when the black limestone is encountered. Only three wells have penetrated more than 1,000 feet of the black limestone. The total normal thickness is estimated to be about 800 feet. This part of the Paleozoic section consists of black, non-porous limestone, commonly dense, although some crystalline zones have been observed. Microfossils are ordinarily observed in the thin sections. Eleven wells have drilled more than 250 feet of black limestone, and, with one possible exception, no encouraging showings of gas or oil were encountered. On this evidence no well has drilled more than 300 feet of "black lime" since 1937.

#### POROSITY MEASUREMENTS

In the Turner Valley field very little coring in the Paleozoic limestone has been undertaken. Extensive coring programs have been carried out in only eight wells. Two of these have been done in the last 3 years, during which time eighty<sup>19</sup> wells have been completed. It is therefore obvious that any average porosity figure for the main producing zones must be determined by the very dubious method of estimates from drill cuttings. Several attempts have been made to classify porous cuttings as "fair porosity," "good porosity," *et cetera*, but the personal error is so great that the results of any such estimates are merely empirical. The writer has devised a method whereby an estimate of the porosity of a sample of porous chips can be made fairly rapidly and the result may be of some value. A marked area of the stage of a binocular microscope is covered with drill cuttings of uniform size. The number of chips that contain definite pores are counted, and this total multiplied by a predetermined factor will result in the "comparative porosity." The factor was determined in the following manner. Core specimens were broken to the size of the drill cuttings used, and the marked area on the stage covered with these fragments. A number of "counts" were then made with the microscope. The factor was obtained by dividing the average of the core fragment "counts" into the measured porosity of the core. There are many obvious discrepancies in this method of estimating porosity, as no consideration is given for the size or the number of the pores. However, the results have been used successfully in a number of acidizing problems, and it is felt that the method is much better than attempting to use descriptive terms.

<sup>19</sup> June, 1936, to June, 1939: 80 wells completed in the limestone; 3 of these were non-commercial.

Paleozoic logs are usually prepared as shown in Figure 10. Whenever the data are available drilling speeds are plotted in conjunction with porosity. In Figure 10 the two wells are only 1,600 feet apart, yet marked differences in the porosity values are obvious. Attempts have been made to delineate areas of high and low porosity, but no reasonable pattern could ever be attained.

Porosity determinations on the core specimens that have been taken range between 1 and 20 per cent, and the average is about 10 per cent for both the upper and lower porous zones. Estimates from cuttings roughly check this average; however, these estimates are *not* considered reliable. All porosity determinations on the core specimens were done by the "grain and bulk density" method.<sup>20</sup> No "effective porosity" determinations have been made.

#### PERMEABILITY

No permeability determinations have been made on any Turner Valley cores. The relative permeability of the producing zones varies widely throughout the field as shown by subsurface pressure data.

In Figure 11 the bottom-hole pressure is plotted against shut-in time for four wells. Locations *B*, *C*, and *D* were chosen, because prior to the build-up tests all three wells had been produced at low back-pressures, and the total amount of oil produced from each was approximately the same. Under comparable conditions the rate of build-up in pressure is a function of the permeability so that the trends of the curves *B*, *C*, and *D* will illustrate the relative permeability at each of these locations. The build-up test *A* was made immediately after the well was completed, and this curve is shown to emphasize the fact that the average permeability is low. Well *A* was one of the largest producers in the field, yet, after a shut-in of 120 hours, the pressure was still building at the rate of  $1\frac{3}{4}$  pounds per hour.

Many other instances could be cited to show the variations in permeability, but in studying subsurface pressure data a complete analysis of producing conditions must be made and presented for each case, and space does not permit this.

Link and Moore<sup>21</sup> were the first to attribute the great variation of production of near-by wells to fracturing. Spratt and Taylor<sup>22</sup> in dis-

<sup>20</sup> H. R. Brankstone, W. B. Gealy, and W. O. Smith, "Improved Technique for Determination of Densities and Porosities," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 9 (September, 1932), pp. 915-23.

<sup>21</sup> Link and Moore, *op. cit.*, p. 1438.

<sup>22</sup> J. Grant Spratt and Vernon Taylor, "Oil Prospects along the West Flank of the Turner Valley Gas Field," *Canadian Inst. Min. Met. Bull.* (1936), pp. 713-22.

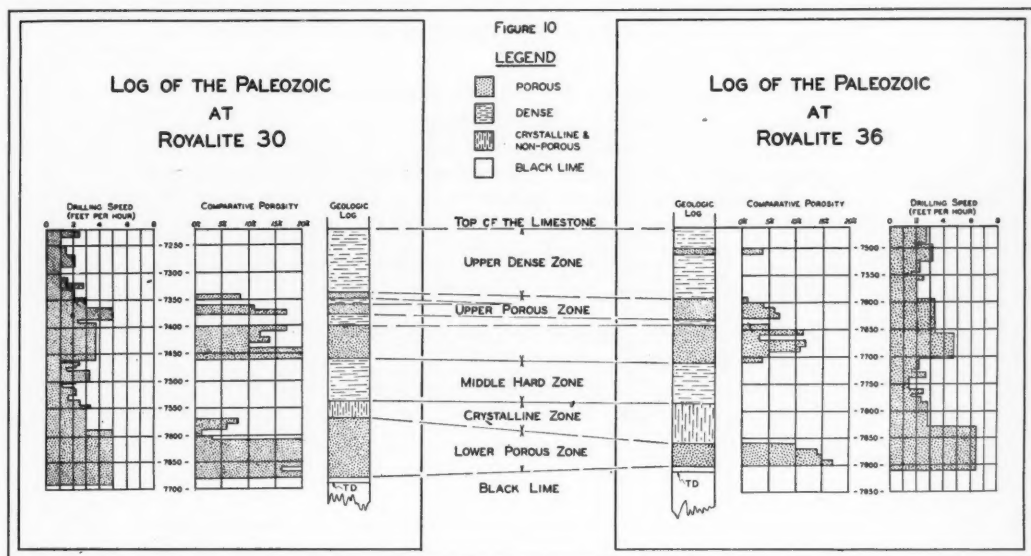


FIG. 10

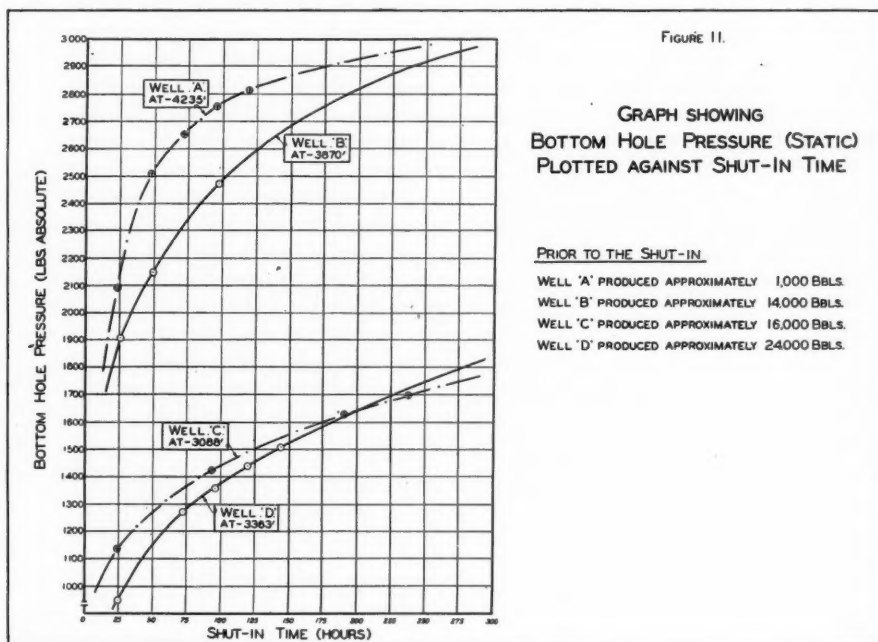


FIG. 11

cussing the importance of fracturing to permeability wrote as follows.

Certain wells have had a very small daily production and at the same time have had just as much porous limestone as that found in some of the best producers in the field. The most logical explanation of this condition is that, in the best producers, the porous zone has been fractured by the stresses prevalent when the structure was being formed . . . . It would be expected that fracturing would be developed along the crest of the structure, where the limestone has been folded, and for this reason a greater degree of permeability may exist in the gas zone than farther down the flank.

There are three types of fracture systems resulting from tension stresses.

1. At the crest of the anticline longitudinal tension fissures were developed when the block was folded. In cross section these fractures will converge from the outer surface of a competent bed toward the core of the anticline, and in plan they will be roughly parallel with the strike.

2. Minor folds and faults involving the Paleozoic limestone do exist and have caused fracturing. However, such secondary structures of any magnitude are very few in number.

3. As the thrust sheet moved eastward at the time of the major dislocation, the resistance of the beds on the downthrown side to the thrust movement was not equal over the entire length of the sheet. Consequently minor tension or tear faults, such as those described by Link,<sup>23</sup> may have occurred. No displacement of a tear fault has ever been defined by the drill. These postulated tear faults may have displacements of only a few inches but since they are tension phenomena they would be sufficient to cause the fractures that are known to exist in the limestone on the west flank of the structure where fractures of types 1 and 2 can hardly be expected.

Often the geologist is subjected to some good-humored criticism when the log of the limestone shows very low porosity and the well is immediately completed as a "big one." The presence of these fractures serves as a convenient and logical explanation.

Recognition of a fracture is simple and definite where an electric-log survey is taken. Both the impedance and potential curves give a decided "kick" opposite a fracture. If a fracture zone exists in a non-porous section, acid will sometimes penetrate it when the well is acidized. One major oil company makes a practice of analyzing the spent acid returned from each treatment. In Table II the results of a few analyses are shown, in which the values of *Ca* and *Mg* have again

<sup>23</sup> Theodore A. Link, "The Origin and Significance of Epi-Anticlinal Faults as Revealed by Experiments," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 8 (August, 1927), pp. 853-66.

been computed to dolomite and calcite by assuming all the *Mg* to be from dolomite. In Royalite No. 41 a fracture in the crystalline zone was indicated in the electric log record and the spent-acid results clearly show that the acid was not spent in the porous dolomite but in a fractured calcitic zone.

Definite slickensided surfaces have been observed in core specimens and drill cuttings from wells on the west flank, giving evidence that minor displacements have taken place and have probably caused some fracturing.

TABLE II  
"MINERALOGICAL BALANCE" OF SPENT-ACID ANALYSIS

Well	Location Sec., Town- ship, R2 W5	Area as in Figure 2	Percentage		Zone Treated
			Calcite	Dolomite	
Royalite 34	5 10	C	2	98	Upper
Royalite 41	17 18	A	59	41	Fracture
Royalite 42	32 18	B	2	98	Upper
Royalite 42	32 18	B	5	95	Upper

Drill-stem tests of the upper porous zone have been made at some locations. In five wells the production from the upper and lower porous zones have been tested separately. The information from all these tests does not show one zone to be consistently more productive than the other. In one well the upper zone may produce most of the oil and gas, in the next, the lower zone will be the main producing bed. However, more data of this nature are required, particularly after the wells have been acidized, and then possibly certain areas can be defined in which the main producing zone can be predicted. From the present conception of the permeability it would seem that varied productivity of the two zones should be expected.

Three wells have been drilled on the west flank of area *E*; two of these are non-commercial and the third, recently completed, gives every indication of being a small well. The permeability of the upper zone in this area is apparently very low, possibly due to precipitation of secondary calcite, while the lower zone is absent, as shown in Figure 2.

#### ACIDIZATION

All crude-oil wells are acidized at least once soon after completion, and many excellent increases have been obtained. The average volume of acid used per treatment is between 7,000 and 10,000 gallons (U.S.). The following geologic data are usually studied before a treating technique is decided upon.

1. *The thickness and approximate average porosity of the producing zones.*—In the initial treatment the volume of acid is often decided on by the thickness and approximate porosity of the porous zones; subsequent volumes are based on the rate of penetration of acid in the first treatment.

2. *The limits of the middle hard zone.*—This information is necessary as most operators acidize with a formation packer set in the middle hard zone so that the acid will be properly directed.

3. *The evidence of any fracturing.*—In some wells it is necessary to prevent acid from penetrating fracture zones, and in such instances the exact location of these zones is of great importance.

4. *The extent of the crystalline zone.*—Although the crystalline zone is non-productive it deserves consideration because of one special condition which might arise in a well that has encountered a thick section of this zone. In an acid treatment of such a well, where a packer is not used or does not maintain a shut-off, it is possible that the acid may rise slowly or fall slowly in the hole. If such is the case the acid may be rapidly spent on the highly soluble calcite before penetration is achieved. The result may be an unsuccessful treatment.

#### SHOOTING WITH NITRO-GLYCERINE

Several of the older wells drilled in the gas cap were shot with nitro-glycerine and in some cases good "increases" were obtained but in others no increase in production resulted from the shots. Only five producing crude oil wells have been shot but the results have been disappointing. In many wells the porous zones are probably too soft to be artificially fractured. However it is quite possible that a technique might be developed whereby the producing zones could be effectively fractured. Present indications are that shooting should be confined to slightly porous or brittle zones where the compressive strength of the formation is considerably greater than the average porous zone.

#### ELECTRIC LOG OF PALEOZOIC LIMESTONE

At the time of writing only a few electric-log surveys of the limestone have been taken and this work is only in the early experimental stage in the Turner Valley field. As previously mentioned, a fracture zone can be readily recognized in any record, but so far this is the only definite information that an electric-log survey contributes to the geological log of the limestone. Since the oil string is cemented approximately 10 feet in the limestone the self-potential values must be measured without using shale as a base line for the obvious reason that

no shale is encountered in the Paleozoic section. In one record there was a difference of only 15 millivolts between the porous zones and the hard dense zones and the maximum self-potential recorded was 25 millivolts. Subsequent production data showed the relative permeability to be better than average. It is estimated that the potential generated by electro-osmosis is negligible. However, investigations on the connate water present in the producing zones has been very limited and possibly this statement may have to be revised when more data are available. In the future the electric log may be of great value to the geologist in Paleozoic studies in the Turner Valley field.

#### CONCLUSIONS

1. The main producing zones in the Turner Valley field are the upper and the lower porous zones of the Rundle or Madison (Paleozoic) limestone; they are both dolomitic and crystalline.
2. The extent of these zones is estimated in the profile shown in Figure 2.
3. The porosity and permeability show wide variations from well to well.
4. Probable secondary calcite crystals in the voids of the dolomite have reduced the permeability and porosity in certain areas.
5. The permeability has been increased in certain areas due to fracturing.
6. Since the average permeability appears to be low, the effective porosity is therefore also low. Because of this, estimates of reserves based on the volumetric method could be misleading.

#### ACKNOWLEDGMENTS

The writer wishes to express his thanks to Theodore A. Link for use of his cross section (Fig. 1) and his assistance in preparation of the manuscript. George de Mille gave valuable assistance in most of the laboratory work; he developed the technique of making thin sections from very soft porous dolomite. The writer also wishes to thank Vernon Taylor for his helpful criticism.

The following data have been made available since submitting the manuscript to the editor.

Between April, 1940, and May, 1940, two wells were completed in Section 18, Township 19, Range 2, West of the 5th Meridian, and one well was completed in Section 13, Township 19, Range 3, West of the 5th Meridian. The limestone sections at these locations show that the north boundary of area *C* in Figure 2 should be moved approximately one mile north.

The results of laboratory work on limestone cores that were recently taken, are summarized as follows.

<i>Zone</i>	<i>Number of Core Samples</i>	<i>Average Porosity in Percent</i>	<i>Number of Core Samples</i>	<i>Average Permeability Millidarcys</i>
Upper porous	4	10.3	—	—
Lower porous	8	12.4	4	17.1

During the first half of 1940 most of the operators in the field reduced the average volume of acid per treatment and increased the number of acid treatments per well.

## LOWER ORDOVICIAN SANDY ZONES ("ST. PETER") IN MIDDLE TENNESSEE<sup>1</sup>

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### ABSTRACT

Several of the deeper wells in the Central Basin and Highland Rim areas of Tennessee have penetrated sandy zones in the Lower Ordovician at depths ranging from 1,250 to 1,600 feet below the Chattanooga shale and from approximately 600 to 950 feet below the base of the Trenton limestones. These zones, which average less than 10 feet in thickness, are composed of subangular to well rounded, glassy, and frosted quartz grains associated with white to gray, granular, and commonly cherty, magnesian limestone and dolomite. This unit has been correlated by some geologists with the St. Peter sandstone of the Mississippi Valley region.

Recent subsurface studies, especially by the insoluble-residue method, have allowed zoning of the pre-Stones River rocks of middle Tennessee. Examination of samples from 30 wells demonstrates that where present the so-called "St. Peter" occurs below the top of the Knox dolomite group of upper Canadian age. These occurrences with relation to established subdivisions of the Knox dolomite group show that the "St. Peter" is not a definite stratigraphic zone although it generally occurs within the upper 300 feet of the Canadian.

### INTRODUCTION

Although the results to date have been generally discouraging, interest persists in the oil and gas possibilities of the Lower Ordovician rocks in the southern Cincinnati arch region. The Tennessee Division of Geology has received numerous requests for information on the St. Peter sandstone in the Nashville dome area due largely to the successful exploitation of its possible stratigraphic equivalent, the "Wilcox" of Oklahoma and Kansas. Considerable difficulty has been experienced in subsurface correlations of the Lower Ordovician section drilled in middle Tennessee. This difficulty is especially pronounced in the interval between rocks definitely known to represent the Stones River group and those previously considered representative of the upper part of the Knox dolomite group of Cambro-Ordovician age.

In an attempt to obtain more definite information on the lithology and stratigraphic relationships of this interval, the Tennessee Division of Geology has initiated detailed subsurface investigations in-

<sup>1</sup> Read before the Association at New Orleans, March 17, 1938. Revised manuscript received, December 26, 1939. Published with the permission of the State geologist.

<sup>2</sup> Assistant geologist, Tennessee Division of Geology. The writer acknowledges with thanks the suggestions of Walter F. Pond, State Geologist, and H. B. Burwell, formerly of the Tennessee Division of Geology. A number of samples were studied by Burwell and to him the writer is indebted for pertinent discussions concerning the subsurface zones described in this paper. Thanks are due E. O. Ulrich, of the United States National Museum, for advice and discussions in the field of a critical pre-Murfreesboro exposure in Sequatchie Valley. Ulrich also identified the small fauna collected at that time. The writer thanks C. W. Wilson, Jr., of Vanderbilt University, for pointing out this exposure.

cluding the insoluble-residue method.<sup>3</sup> Since it will be some time before these subsurface studies on the pre-Trenton rocks are completed, it is believed that the present interest in the St. Peter sandstone east of the Mississippi River justifies a brief discussion of the present status of the "St. Peter" in Tennessee, including a summary of the existing data and some suggestions as to possible correlations with the standard Lower Ordovician section. The general conclusions have been based upon detailed examinations of 30 wells in middle Tennessee which have entered Canadian rocks (Fig. 1).

#### PREVIOUS WORK

A number of the deeper wells in southern Kentucky have logged sandstones or sandy limestones which have been correlated by Munn<sup>4</sup> and by Shaw and Mather,<sup>5</sup> with the St. Peter sandstone of the upper Mississippi Valley region. This zone is in the lower part of the Ordovician system of Kentucky, and occurs from 1,470 to 1,600 feet below the Chattanooga shale. The existence of similar zones of sandy magnesian limestone and dolomite, at depths ranging from 1,250 to 1,600 feet below the top of the Chattanooga shale, has been proved by more than 50 tests drilled in middle Tennessee between the Cumberland Plateau and the Mississippi Embayment region. These zones have been referred to the St. Peter sandstone by several geologists and the name has become firmly entrenched in the vocabulary of oil men in the state.

Although the trade journals had repeatedly suggested the presence of the St. Peter sandstone in Tennessee, it was not until 1931 that subsurface studies were made of this zone. In that year, Bailey<sup>6</sup> tentatively correlated a sandy limestone or sandstone, below a "greenish shaly limestone" and approximately 800 feet below the base of the Trenton, as the St. Peter sandstone. He described this horizon as consisting "largely of well-rounded, glassy or frosted grains of quartz in a matrix of white, granular, magnesian limestone." The following year, Piper<sup>7</sup> reported sandy strata encountered in wells in north-cen-

<sup>3</sup> With the exception of minor deviations generally necessary for local areas, the procedure used in the insoluble-residue studies is the same as developed and described by McQueen. See H. S. McQueen, "Insoluble Residues as a Guide to Stratigraphic Studies," *Missouri Bur. Geol. Fifty-Sixth Bien. Rept.* (1931), pp. 104-07.

<sup>4</sup> M. J. Munn, "Reconnaissance of Oil and Gas Fields in Wayne and McCreary Counties, Kentucky," *U. S. Geol. Survey Bull.* 579 (1914), p. 17.

<sup>5</sup> E. W. Shaw and K. F. Mather, "The Oil Fields of Allen County, Kentucky," *U. S. Geol. Survey Bull.* 688 (1919), p. 39.

<sup>6</sup> W. F. Bailey, "Notes on Subsurface Stratigraphy of Middle Tennessee," *Jour. Tennessee Acad. Sci.*, Vol. 6 (1931), pp. 80-88.

<sup>7</sup> A. M. Piper, "Ground-Water in North-Central Tennessee," *U. S. Geol. Survey Water-Supply Paper* 640 (1932), p. 61.

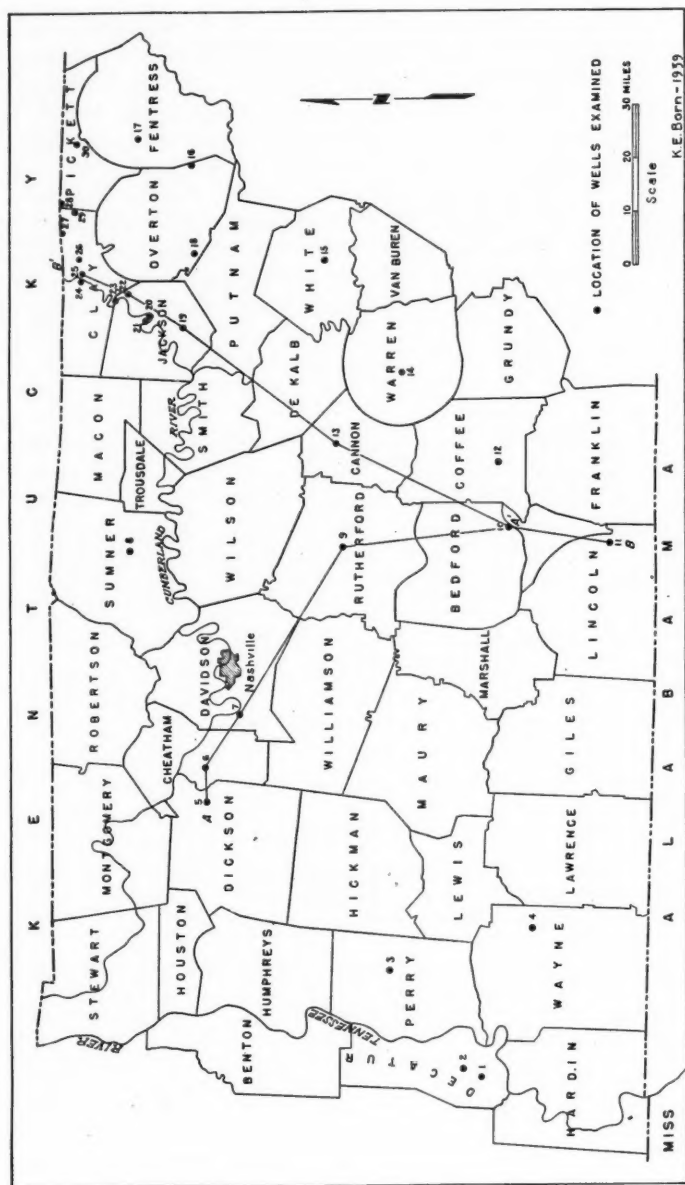


FIG. 1.—Sketch map of middle Tennessee showing location of wells studied. Lines AA' and BB' indicate locations of cross sections in Figures 8 and 9, respectively.

tral Tennessee and termed them St. Peter (?). In the same year, Bassler<sup>8</sup> suggested that deeper wells in the Central Basin of Tennessee might pass through the St. Peter sandstone before entering the underlying Canadian dolomites. In 1935, Bailey,<sup>9</sup> in discussing the sub-Trenton gas possibilities in the southern Cincinnati arch region, again tentatively correlated a "hard, white, sandy limestone at depths of 1200-1400 feet below the Chattanooga shale" as St. Peter. In a recent study of the ground-water resources of south-central Tennessee, Theis<sup>10</sup> described "a sandy limestone, in places perhaps a real sandstone, lying about 1500 feet below the Chattanooga shale at Nashville, and apparently about 600 feet below the top of the Murfreesboro limestone at Murfreesboro." He states that this bed has been doubtfully correlated with the St. Peter. In 1936, Born<sup>11</sup> described the so-called "St. Peter" horizon in Tennessee and mention was made of it again the following year.<sup>12</sup>

Insoluble residue studies by Meacham<sup>13</sup> from several deep wells in Kentucky indicated the presence of a very pure white quartz sand below the Stones River group of limestones and above the Canadian in several counties in the north-central part of the state. This sandstone was correlated with the St. Peter sandstone of the Mississippi Valley region. Recently, Jillson<sup>14</sup> has suggested that this same sandstone was penetrated in several additional counties, including Wayne and Clinton, whose southern boundary is the Tennessee state line. Another possible correlation of these Lower Ordovician beds in southern Kentucky is considered later in this paper.

In northern Alabama, Butts<sup>15</sup> reports the Odenville limestone of upper Canadian age overlain unconformably by beds of Chazy (Stones River) age with the complete absence of the St. Peter sandstone and

<sup>8</sup> R. S. Bassler, "Stratigraphy of the Central Basin of Tennessee," *Tennessee Div. Geol. Bull.* 38 (1932), p. 48.

<sup>9</sup> W. F. Bailey, "Natural Gas from Paleozoic Horizons in Southern Cincinnati Arch Region," *Geology of Natural Gas* (Amer. Assoc. Petrol. Geol., 1935), pp. 857-58.

<sup>10</sup> C. V. Theis, "Ground-Water in South-Central Tennessee," *U. S. Geol. Survey Water-Supply Paper* 677 (1936), pp. 79-80.

<sup>11</sup> K. E. Born, "Oil and Gas Developments in Tennessee in 1935," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 118 (1936), pp. 351-52.

<sup>12</sup> K. E. Born, "Oil and Gas Developments in Tennessee in 1936," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 123 (1937), p. 453.

<sup>13</sup> R. P. Meacham, "A Stratigraphic Analysis of Some Deep Well Records in Kentucky," *Univ. of Kentucky Bull.* 2 (1933), pp. 3-4.

<sup>14</sup> W. R. Jillson, *The Saint Peter Sandstone in Kentucky* (Standard Printing Company, Louisville, 1938), pp. 23-25.

<sup>15</sup> Chas. Butts, "Geology of Alabama," *Geol. Survey of Alabama Spec. Rept.* 14 (1926), p. 101.

associated beds. Sandstones encountered in tests into the Lower Ordovician in northeastern Mississippi have been considered as Beekmantown (Canadian) or pre-Beekmantown by Bramlette.<sup>16</sup>

#### TERMINOLOGY USED IN PRESENT STUDY

Although more than 90 wells have been drilled into the Knox dolomite group in central Tennessee, samples are available on about one-third of these tests. Few wells have been drilled farther than 100 feet below the base of the Stones River group, due largely to a common practice of abandoning oil and gas tests at or near the top of the Knox dolomite group. Incomplete sample sets, the distance removed from the Lower Ordovician outcrop, and the absence of deep intervening wells are the chief factors contributing to the indefinite correlations of the pre-Stones River rocks which underlie the Central Basin and Highland Rim regions of Tennessee. In the present study it has seemed advisable, therefore, to consider the Lower Ordovician beds as zones, which, following Hiestand,<sup>17</sup> have been assigned alphabetical designations, following the custom of plane-table surveying where the subdivisions have not been traced continuously to type localities of formational outcrops. No fossil fragments have been observed in samples below the base of the Stones River group (Zone A). These zones, therefore, have been based entirely on the microlithology of original well samples and the microcharacteristics of insoluble residues. While more detailed surface and subsurface data will be necessary to demonstrate precise correlations, there is a strong suggestion that these subsurface zones do have stratigraphic significance. The general lithologic character of the original samples and characteristic insoluble residues which constitute these zones are shown in Figure 2.

#### PRE-TRENTON STRATIGRAPHY OF MIDDLE TENNESSEE

##### MOHAWKIAN SERIES

##### BLACK RIVER GROUP

The deeper wells in middle Tennessee, especially east of the Nashville arch, penetrate a widespread stratigraphic marker at a depth of approximately 500 feet below the base of the Chattanooga shale. This marker, a thin bed of green, bentonitic clay, occurs near the top of the Carters limestone, the only Black River representative in middle Tennessee, and usually less than 15 feet below the base of the Trenton limestones and shales. The tendency of this thin clay-shale to cave

<sup>16</sup> M. N. Bramlette, "Paleozoic Formations Penetrated by Wells in Tishomingo County, Northeastern Mississippi," *U. S. Geol. Survey Bull.* 781-A (1926), p. 8.

<sup>17</sup> T. C. Hiestand, "Studies of Insoluble Residues from 'Mississippi Lime' of Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22 (1938), p. 1591.

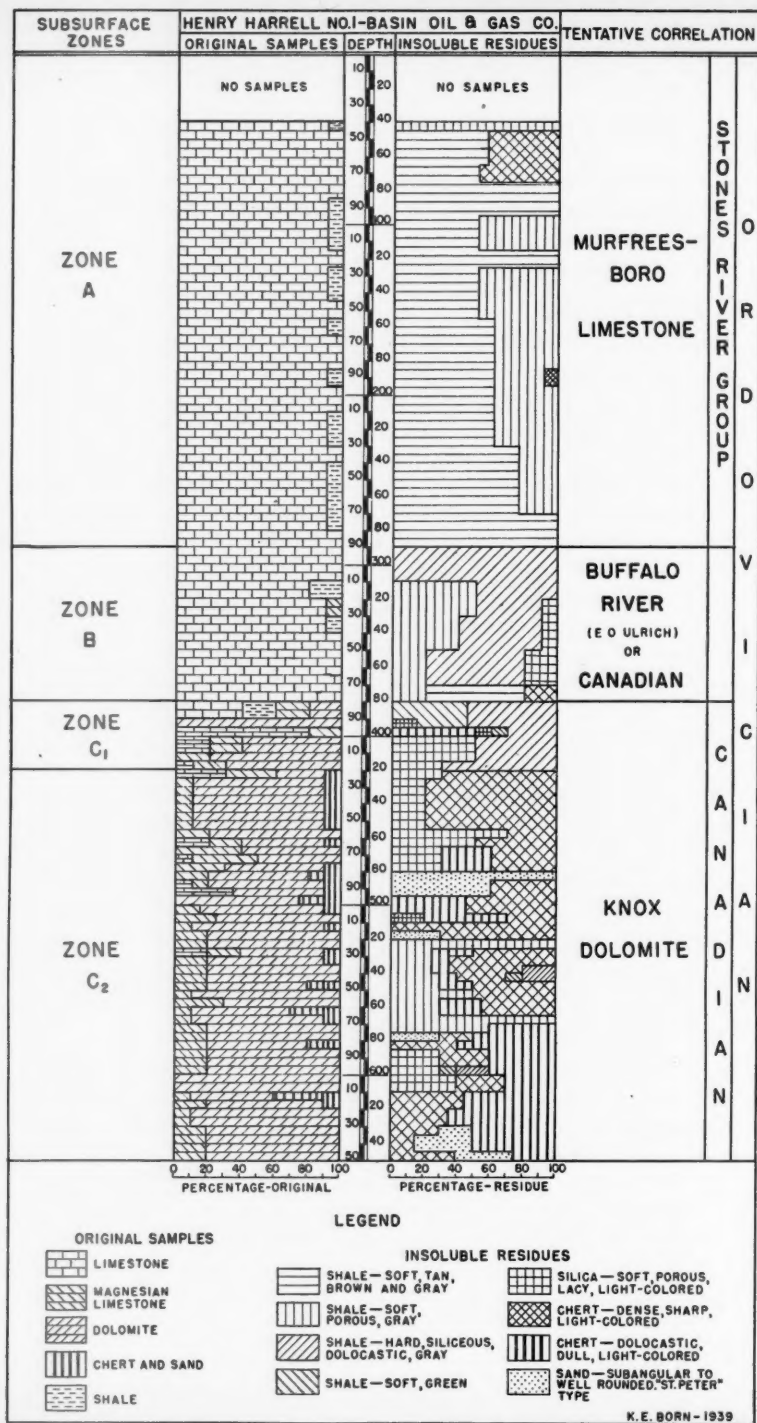


FIG. 2.—Graph of original samples and insoluble residues and correlations of pre-Stones River rocks in Basin Oil and Gas Company's Henry Harrell No. 1 (No. 9 in Figure 1).

into wells in pencil-shaped fragments has given rise to the name Pencil Cave which has become so well established among drillers in Kentucky and Tennessee. East of the Nashville arch it is the most important subsurface marker in the Ordovician section; on the western flank of the arch it is very thin and in many places absent.

Two members are recognized in the Carters limestone on the outcrop in middle Tennessee.<sup>18</sup> The lower member is defined as that part of the Carters limestone between the persistent bentonite bed (Pencil Cave of the driller) and the top of the underlying Lebanon limestone. Lithologically, this member consists of light to dark gray, dense to medium-grained limestone, some of which is magnesian. Bedding is generally massive. The average thickness on the outcrop in middle Tennessee is about 50 feet. The upper member consists of beds from the top of the bentonite to the base of the Hermitage formation of the Trenton group. It is a thin-bedded, dense to fine-grained, light gray limestone.

This two-fold division of the Carters limestone is well developed in the subsurface throughout middle Tennessee, especially east of the Nashville arch. The entire unit reaches a maximum thickness of approximately 100 feet in wells.

#### CHAZYAN SERIES STONES RIVER GROUP

In the type area in the Central Basin the Stones River group reaches a maximum thickness of 318 feet on the outcrop.<sup>19</sup> The section is predominantly gray to dark gray, tan, and brown, dense to medium-grained limestone. Thin, gray, and tan, calcareous shale beds and partings are commonly present between the limestones, but they make up a relatively small part of the unit. Chert is present, but not common. In the Central Basin four formations are recognized, in ascending order: the Murfreesboro, Pierce, Ridley, and Lebanon limestones.

Subsurface studies of well samples from the deeper tests in central Tennessee indicate thicknesses of more than 700 feet for the Stones River group, although the average thickness is somewhat less than this figure. In Decatur County the Chester County Oil Company's J. A. Montgomery No. 1 (1)\* and the Standard Oil Company of Louisiana's C. W. Wyatt No. 1 (2) penetrated approximately 600 feet of

<sup>18</sup> C. W. Wilson, Jr., "Stones River and Black River Groups in Central Tennessee," *Tennessee Div. Geol.*, unpublished manuscript (1938).

<sup>19</sup> J. J. Galloway, "Geology and Natural Resources of Rutherford County, Tennessee," *Tennessee Geol. Survey Bull.* 22 (1919), p. 30.

\* Numbers in parentheses refer to well locations in Figure 1.

beds between the base of the Trenton and the top of the unit here considered as Zone C<sub>1</sub>. In general, however, throughout middle Tennessee the Stones River group is remarkably constant in thickness.

The marked lithological similarity of this group in the subsurface makes it difficult to subdivide the Stones River group into its component formations. The entire section from the Pencil Cave horizon at the top of the lower member of the Carters limestone to the top of a unit, considered below as Zone B, constitutes a single lithologic unit in the subsurface. No well defined subdivisions of this section have been possible in microscopic examinations of original samples from test wells. In connection with recent subsurface studies of this group in Clay and adjoining counties in the Upper Cumberland district of Tennessee and Kentucky, insoluble residues have permitted the definition of several diagnostic markers in the Black River and Stones River groups.<sup>20</sup> Detailed studies of these residues are now in progress to determine whether or not they are true stratigraphic markers throughout central Tennessee. Only one of them, described here as Zone A, is pertinent to the present study.

#### ZONE A

*Original samples.*—Untreated samples from the lower part of the Stones River limestones throughout middle Tennessee consist essentially of drab-gray and tan to brown, dense to medium-grained limestones with minor amounts of hard to soft, dense, calcareous, and siliceous gray shale. Dark gray and brown are the predominating colors of both the limestone and shale. Minor constituents include white calcite, gypsum, and small amounts of generally dark gray, dense, sharp chert. Pyrite is in places associated with the darker limestones. Fresh samples commonly have a distinct odor of petroleum.

*Insoluble residues.*—In contrast with untreated samples, insoluble residues prepared from cuttings of wells which have entered the lower Stones River indicate a persistent residue unit (Fig. 3). Shales are the major constituents of the residues; they are generally medium to dark gray, tan, and medium to dark brown in color, soft, dull, lumpy, porous, and in places finely doloclastic. Chert is rare, but where present it is ordinarily dark, dense, and angular. Other minor constituents include pyrite, dull, soft, porous, gray siltstone, and rarely poorly preserved silicified fossil fragments, ordinarily gastropods and bryozoans. By volume, the residues of this unit range from 10 to about 25 per cent, with an average of approximately 15 per cent.

<sup>20</sup> K. E. Born and H. B. Burwell, "Geology and Petroleum Resources of Clay County, Tennessee," *Tennessee Div. Geol. Bull.* 47 (1939), pp. 33-38.

*Thickness.*—Since this zone is significant in the present discussion only in that it marks the lower part of the Stones River group, the entire unit has not been studied in detail in each well. In the Basin Oil and Gas Company's Henry Harrell No. 1 (9) in Rutherford County it is 285 feet thick and in Jesse Ashby *et al.* Donaldson Heirs No. 1 (25) in Clay County 380 feet of strata are assigned to this zone.

*Correlation.*—In Rutherford County, near the center of the Nashville dome, approximately 70 feet of Murfreesboro limestone are ex-



FIG. 3.—Light gray, soft, porous, slightly doloclastic shale residues of Zone A. Depth, 1,130 feet, E. H. Crow *et al.* B. Y. Brown No. 1 (No. 5 in Figure 1). (X20.)

posed. Here the upper 10–30 feet of the limestone contain dark, dense chert and the top of the Murfreesboro has been tentatively drawn in the subsurface at the first appearance of a considerable amount of similar dark, angular, vitreous, dense chert in samples. Chip samples from below the chert horizon on the outcrop give residues generally identical with those previously described under Zone A.

At several places in Sequatchie Valley in Bledsoe and Marion counties, the base of the Murfreesboro is well exposed. Lithologically and faunally the rocks are very similar to the Murfreesboro of the Central Basin.<sup>21</sup> Residues of chip samples from three sections in

<sup>21</sup> C. W. Wilson, Jr., *op. cit.*

Sequatchie Valley are strikingly similar to those from Zone A as developed in middle Tennessee. Zone A is, therefore, considered to represent the lower and greater part of the Murfreesboro limestone and the base of the Stones River group in the subsurface in middle Tennessee is drawn at the base of characteristic residues of Zone A. The cross sections in Figures 8 and 9 are constructed with the base of this zone as the datum.

BUFFALO RIVER SERIES OF E. O. ULRICH  
OR CANADIAN SERIES  
ZONE B

*Original samples.*—In all wells drilled below the base of the Stones River group (Zone A) in central Tennessee, the dark gray and brown limestones give way rather sharply below into a unit of generally light-colored limestones. The limestones are dense and vaughnitic to fine-grained. Light gray and light tan are the predominating colors. Many of the dense limestones show clear calcite inclusions, not unlike the "birdseye" limestones of the Black River group. Shale and chert are rare and are seldom observed in untreated samples. Clear and white calcite and selenite are the most common minor constituents. No fossils have been noted in this unit.

In many of the samples the staining method described by Keller and Moore<sup>22</sup> indicates the presence of minor amounts of magnesian and dolomitic limestone, although no true dolomites have been observed in samples studied to date. A series of chemical analyses through this unit in Jesse Ashby *et al.* Donaldson Heirs No. 1 (25) shows a maximum of 5.67 per cent magnesium carbonate. The 1,225-foot sample from the Carnahan Oil Company's Joe D. Moredock No. 2 (29) analyzed 9.52 per cent magnesium carbonate.

*Insoluble residues.*—Quantitatively the insoluble residues from Zone B are in sharp contrast with those above and below this unit. By volume they seldom exceed 5 per cent of the original sample and the average is less than this figure. Chemical analyses of samples from this zone indicate that the limestones are nearly pure with usually less than 5 per cent insoluble matter.

The characteristic residues of Zone B are shales and minor amounts of siltstones or siliceous aggregates (Fig. 4). The shales are of two types: (1) a soft, light-colored, usually gray, rarely greenish gray, porous, lumpy shale, somewhat similar in general appearance to cer-

<sup>22</sup> W. D. Keller and George E. Moore, "Staining Drill Cuttings for Calcite-Dolomite Differentiation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21 (1937), pp. 949-51.

tain of the gray shale residues of Zone A; and (2) a hard, light gray, siliceous shale, much of which shows minute dolocasts. The latter variety is generally the better developed. Soft, porous, lacy and fragile, light-colored silica and siliceous aggregates are the most characteristic residues of Zone B, although they are commonly subordinate in amount to the shale.

*Thickness.*—In the 30 wells studied Zone B varies from 20 to 95 feet in thickness. The maximum thickness occurs in the Western Val-

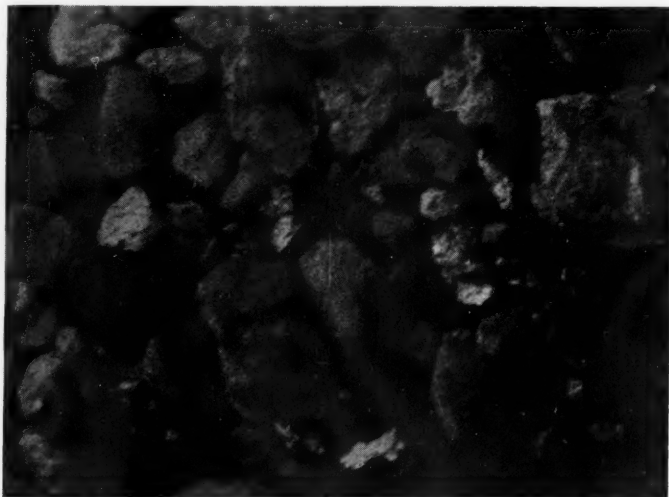


FIG. 4.—Characteristic white, gray, and tan siltstones and siliceous aggregates from Zone B. Depth, 330-340 feet, Basin Oil and Gas Company's Henry Harrell No. 1 (No. 9 in Figure 1). ( $\times 20$ .)

ley of the Tennessee River in the Chester County Oil Company's J. A. Montgomery No. 1 (1). Three other wells (2, 3, 4) on the southwest flank of the Nashville dome penetrated more than 75 feet of this unit. A rather constant thickness of 40 feet is indicated by four wells (5, 6, 7, 8) on the northwest flank of the Nashville arch. Near the center of the Nashville dome, in the Basin Oil and Gas Company's Henry Harrell No. 1 (9), 80 feet of beds are referred to Zone B. East of the arch this unit varies in thickness from a minimum of 20 feet in the Ava Oil and Gas Company's Mary Williams No. 3 (26) in eastern Clay County to a maximum of 91 feet in the Jervian Corporation's J. T. Keithley No. 1 (15) in southern White County.

*Correlation.*—At present the exact relationship of Zone B to the overlying Stones River group and the underlying rocks, definitely of Canadian age, is not well understood. This unit is probably exposed in the Wells Creek Basin of southeastern Stewart County, but it has not been definitely recognized, due largely to the intense deformation of the area and poor exposures of the section between the upper part of the Knox dolomite and Trenton groups. In the southern Appalachian region the Canadian is directly overlain by rocks of Chazy age, with no suggestion of the presence of beds of the Buffalo River group of Ulrich.<sup>23</sup>

In Bledsoe and Sequatchie counties in the Sequatchie Valley a distinctive series of light-colored, generally light gray, thick- to thin-bedded, dense to vaughnitic and fine-grained limestones overlie a section of dolomite and dolomitic limestone—definitely a part of the upper Knox dolomite group—and underlie dense to fine-grained, dark gray limestones correlated with the Murfreesboro limestone of the Central Basin.<sup>24</sup> In three sections measured, sampled, and studied, these light-colored, dense limestones averaged 160 feet in thickness. Lithologically, this unit has much in common with subsurface samples from Zone B in middle Tennessee. While not identical throughout, insoluble residues, prepared from chip samples from three sections, compare favorably in their general assemblage with those from Zone B.

The writer has considered two possible correlations of these pre-Stones River limestones in the Sequatchie Valley: they may be a part of the Newala limestone of northern Alabama or they may represent a previously unrecognized formation.<sup>25</sup> In Alabama the Newala limestone is described by Butts<sup>26</sup> as a "thick-bedded, compact or non-crystalline or textureless, dark-gray, pearl-gray, and bluish-gray" limestone. It is composed of much limestone and proportionately little dolomite. On the basis of its fauna, the Newala has been correlated with the Cotter formation of upper Canadian age.<sup>27</sup> In the microscopic examinations of samples from some of the deeper wells in the Upper Cumberland district, in Clay and near-by counties, the presence of magnesian limestones and soft, dull, greenish gray shales, typically developed in the underlying Knox dolomite group, suggested the refer-

<sup>23</sup> E. O. Ulrich, "Ordovician Trilobites of the Family *Telephidae* and Concerned Stratigraphic Correlations," *U. S. National Museum*, Vol. 76 (1929), pp. 78-79.

<sup>24</sup> C. W. Wilson, Jr., *op. cit.*

<sup>25</sup> K. E. Born and H. B. Burwell, *op. cit.*, pp. 28-29.

<sup>26</sup> Chas. Butts, *op. cit.*, p. 93.

<sup>27</sup> Chas. Butts, *op. cit.*, pp. 98-99.

ence of Zone B to the upper Canadian. Such a correlation was questionably indicated by Born and Burwell.<sup>28</sup>

In May, 1939, the writer, with E. O. Ulrich of the United States National Museum and R. D. Mesler of the United States Geological Survey, revisited the best exposure of this pre-Stones River unit in the Sequatchie Valley. This section, located 2.1 miles east of Daus in Sequatchie County, and south of the Sequatchie River, presents almost continuous exposures from the upper 250 feet of the upper Canadian to near the top of the Stones River group. The pre-Stones River unit is particularly well exposed. In the field Ulrich recognized similarities of these limestones with the Everton formation of the Lower Ordovician (Buffalo River group of E. O. Ulrich) in northeastern Arkansas. Subsequent laboratory identifications of a small fauna collected revealed three genera of gastropods, *Raphistoma*, *Holopea*, and *Hormotoma*, all new species, and an undescribed species of the ostracod *Isochilina*. All four species have been listed by Ulrich in the Everton limestone collections from northeastern Arkansas.<sup>29</sup> This unit, is, therefore, correlated with the Everton formation of northeastern Arkansas and represents the first recognition of the Buffalo River group in Tennessee.<sup>30</sup>

Though most of the original samples and insoluble residues from Zone B compare favorably with chip samples and residues from the Everton limestone in Sequatchie Valley, more detailed surface and subsurface studies will be required before this correlation may be definitely established. The typical Canadian green shales commonly present in the lower part of Zone B have not been recognized in outcrops of the Everton limestone in Sequatchie Valley. Furthermore, the limestones of Zone B are considerably more magnesian than exposures of the Everton examined to date. Until more data are available the writer is, therefore, hesitant to abandon completely the possibility of an upper Canadian age for this pre-Stones River unit.

CANADIAN SERIES  
(CANADIAN SYSTEM OF E. O. ULRICH)  
KNOX DOLOMITE GROUP  
GENERAL STATEMENT

The oldest rocks drilled to date in the Central Basin and Highland Rim areas of Tennessee are a part of the Knox dolomite group of

<sup>28</sup> K. E. Born and H. B. Burwell, *op. cit.*, p. 29.

<sup>29</sup> E. O. Ulrich, written communication, August 11, 1939.

<sup>30</sup> E. O. Ulrich, "The Murfreesboro Limestone in Missouri and Arkansas and Some Related Facts and Probabilities," *Kansas Geological Society Guidebook 13th Annual Field Conference* (1939), correlation table, p. 106.

Cambro-Ordovician age (Canadian and Ozarkian systems of E. O. Ulrich). This group crops out in wide areas in the Appalachian area of east Tennessee where it is composed of white, gray, blue, and brown limestones, magnesian and dolomitic limestones, and gray to tan and brown dolomites. Cherts are common and are abundant at certain horizons. Thin sandstones and shales are locally developed. The thickness of this group reaches more than 4,000 feet in east Tennessee. To the west the Knox passes beneath younger beds, but in the Basin Oil and Gas Company's Henry Harrell No. 1 (9) at Murfreesboro, near the top of the Nashville dome, tan dolomites, considered to mark the top of the Knox dolomite, were encountered at 370 feet. About 75 miles northwest of Nashville, in the Wells Creek Basin in southeastern Stewart County, the Knox dolomite group appears at the surface in a local intensely disturbed area.<sup>21</sup> The thickness of the Knox dolomite group in middle Tennessee is not known; the deepest well, stratigraphically, is the Franklin Fuel and Oil Company's J. M. Alsop No. 1, at Murfreesboro in Rutherford County, in which 1,910 feet of Knox dolomite were drilled without reaching the base of the group.

#### ZONE C<sub>1</sub>

*Original samples.*—In most wells drilled into the Canadian in middle Tennessee Zone B is underlain by a group of beds composed of light gray to greenish gray, tan and brown, fine- to coarse-grained dolomite and light gray magnesian limestone. Chert is rare, which is a striking contrast to the underlying section. Minor constituents include light to dark grayish green shale and small amounts of silica and siliceous aggregates, undoubtedly secondary in origin. Subangular to well rounded, pitted, and frosted quartz grains occur sporadically throughout this zone, but in few places in concentrations of more than 5 per cent. Much of the sand is free in the samples, although quartz grains imbedded in shale and sandy dolomite are not uncommon. Zones in which the sand grains are concentrated have been termed "St. Peter," regardless of their stratigraphic position with reference to well established subsurface markers.

*Insoluble residues.*—Green shales are the characteristic residuals of Zone C<sub>1</sub> (Fig. 5). The shales are of two types: (1) light to dark grayish green, soft, thinly laminated shale with a dull luster; and (2) dark green to bluish green, dense, hard, generally doloclastic shale. The former appears similar to the bentonitic Pencil Cave, although

<sup>21</sup> J. M. Safford, *Geology of Tennessee*, Nashville (1869), p. 147.

W. H. Bucher, "Cryptovolcanic Structures in the United States," *XVI Int. Geol. Cong. Rept.*, Vol. 2 (1936), pp. 1066-70.

no biotite flakes have been observed in it to date. The hard green shale is commonly studded with small subangular to well rounded quartz grains. Associated with these green shales are other shale fragments which may be light gray to brown, commonly doloclastic, and generally soft. Soft, lacy, light-colored silica and spongy pyrite are common in some of the samples. By volume the residues of Zone C<sub>1</sub> average less than 15 per cent of the original samples.

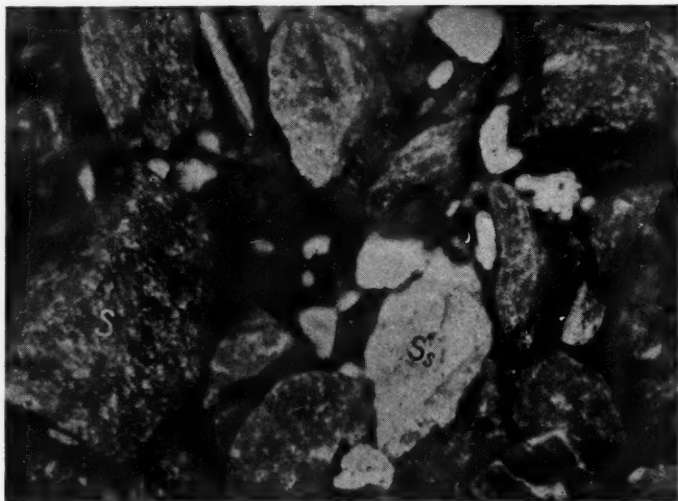


FIG. 5.—Gray to greenish gray, siliceous, rounded shale residues (S) with porous, doloclastic siltstone (Ss) from Zone C<sub>1</sub>. Depth, 1,137–42 feet, W. F. Carter *et al.* Thomas Scantland No. 1 (No. 22 in Figure 1). ( $\times 20$ .)

*Thickness.*—Zone C<sub>1</sub> varies considerably in thickness in the wells studied. It is apparently absent in three wells in Clay County, the Ava Oil and Gas Company's Mary Williams No. 3 (26), Carnahan Oil Company's Joe D. Moredock No. 2 (29), and in the Lain Oil and Gas Company's T. W. Roberts No. 2 (24). Near the center of the Nashville dome the Basin Oil and Gas Company's Henry Harrell No. 1 (9) penetrated 40 feet of beds assigned to this zone. The maximum thickness indicated by the present study is in the Western Valley of Tennessee River where the Standard Oil Company of Louisiana's C. W. Wyatt No. 1 (2) encountered 178 feet of gray, tan, and brown sucrose dolomite above the cherty dolomites here considered to mark the top of Zone C<sub>2</sub>. Throughout most of the state, however, this unit averages approximately 65 feet in thickness.

*Correlation.*—No fossil fragments have been observed in samples from Zone C<sub>1</sub>. On the basis of the predominance of dolomite and characteristic green shales, this unit is correlated with the upper part of the Knox dolomite group. Green shales, almost identical with those previously described, have been observed interbedded with dolomite and magnesian limestones in the Sequatchie Valley and in the Appalachian region. This unit is probably the "green lime" of Bailey.<sup>32</sup>

The almost complete absence of chert in this zone in the subsurface throughout middle Tennessee is in marked contrast with typical exposures of the upper part of the Knox dolomite group in the Appalachian region. While the exact age of this unit is unknown, it may well represent younger Canadian beds than any observed to date in east Tennessee. Zone C<sub>1</sub> is probably represented by the non-cherty magnesian limestones and dolomites which are poorly exposed on the northwest flank of the Wells Creek uplift in southeastern Stewart County.

#### ZONE C<sub>2</sub>

*Original samples.*—The relatively pure dolomites and dolomitic limestones of Zone C<sub>1</sub> are underlain by a distinctive and thick section of dolomites, dolomitic and magnesian limestones, with much chert. The dolomite is generally light in color, grays, tans, and browns predominating. The texture varies from fine- to coarse-grained, although the medium- and coarse-grained dolomites are the more common. The dolomitic and magnesian limestones are ordinarily gray and dense to fine-grained. Lithologically, they are generally similar to the dense limestones of Zone B. Chert is a common constituent of this unit, which is in striking contrast with the overlying section. The cherts are described in more detail below. A soft, bentonitic (?), light green shale, which is commonly present in the overlying unit, continues into this zone.

*Insoluble residues.*—Chert is by far the most abundant insoluble residue of Zone C<sub>2</sub> (Fig. 6). The colors vary from white to milky to tan; darker colors are rare, although a distinctive brown oölitic chert has been observed in a number of samples. The chert is angular, sharp, generally dense, and commonly translucent. Oölitic varieties are present, although they are common in only a few places. A few of the fragments show concentric banding. Chalky white, soft chert, in many places doloclastic, is a common constituent of the upper 50 feet of this unit. While doloclastic cherts are present throughout this zone,

<sup>32</sup> W. F. Bailey, "Notes on Subsurface Stratigraphy of Middle Tennessee," *Jour. Tennessee Acad. Sci.*, Vol. 6 (1931), p. 82.

they appear to reach their maximum development about 100 feet below the top of this unit.

In a number of wells, concentrations of well rounded, pitted and frosted quartz grains of the "St. Peter" type are associated with the cherts. Minor constituents of this zone include porous sponge-like pyrite and soft, porous, greenish gray siltstone, or siliceous aggregate.

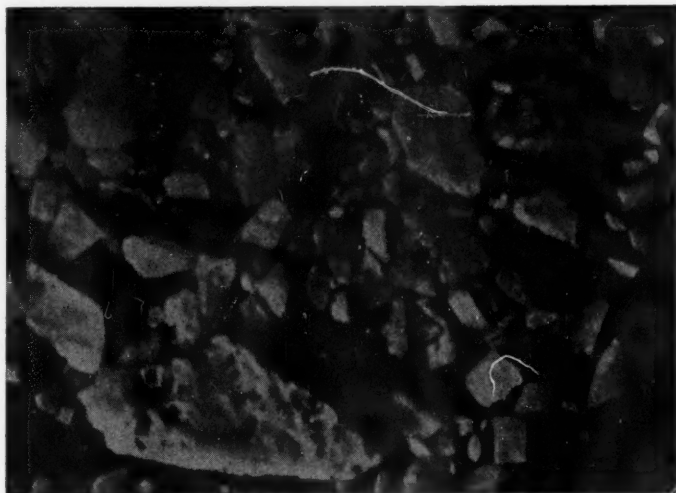


FIG. 6.—Typical light-colored, dense, angular chert residues of Zone C<sub>2</sub>. Note oölitic varieties in right center. Depth, 1,257–62 feet, Jesse Ashby *et al.* Donaldson Heirs No. 1 (No. 25 in Figure 1). (X20.)

*Thickness.*—Since relatively few wells in Tennessee have been drilled more than 200 feet into the Knox dolomite group, the thickness of this unit is not definitely known. Deeper drilling will undoubtedly make it possible to subdivide these beds into residue units.

*Correlation.*—The lithologic character of the original samples from Zone C<sub>2</sub> throughout middle Tennessee is identical with that of the upper part of the Knox dolomite group of Canadian age which crops out in the Appalachian region of eastern Tennessee and with rocks of Canadian age (Wells chert of E. O. Ulrich) exposed near the center of the Wells Creek Basin in southeastern Stewart County. The residues of this zone compare remarkably well with those described by Oder<sup>33</sup> from the Cotter-Powell beds of Canadian age in the Great

<sup>33</sup> C. R. L. Oder, "The Stratigraphy, Structure, and Paleontology of the Zinc-Bearing Knox Dolomite between Jefferson City and Bristol, Tennessee," *Tennessee Div. Geol.* (unpublished manuscript, 1933).

Valley region of east Tennessee. In general, the insoluble residue assemblage compares favorably with that described by McQueen<sup>34</sup> and Meacham<sup>35</sup> from the lower part of the Cotter formation of Missouri and Kentucky, respectively. Until additional subsurface data are available, however, which will allow more definite correlations, this unit will be designated as Zone C<sub>2</sub> of the Knox dolomite group. Studies to date indicate that it is a widespread unit underlying middle Tennessee, and it has been traced in the subsurface from the Western Valley of Tennessee River to the western part of the Cumberland Plateau.

#### SANDY ZONES IN KNOX DOLOMITE GROUP

*General statement.*—Examinations of 30 sample sets in middle Tennessee have shown the presence of arenaceous zones in the pre-Stones River rocks. These consist of subangular to well rounded, generally pitted and frosted, quartz grains associated with magnesian limestones and dolomites and commonly with characteristic cherts of the Knox dolomite group. No true sandstones have been observed to date. The sand content of few samples constitutes more than 10 per cent, although in a few wells concentrations reach as much as 40 per cent. That these zones have a certain amount of porosity is evidenced by the numerous salt water, sulphur water, oil and gas showings, and some oil and gas production.

*Lithology.*—Although varying in amounts and size, the sands in the Lower Ordovician are remarkably constant in their general character (Fig. 7). The size of grain varies from about 0.1 to nearly 1.0 millimeter, with an average of about 0.3–0.5 millimeter. The greater number of the grains are well rounded, although subangular varieties are not uncommon. Frosting and pitting are common, although the subangular grains exhibit these features to a lesser degree. Some of the grains show secondary enlargement.

The mineralogic associations of the quartz grains vary widely even between relatively close wells. Magnesian limestones, dolomites, cherts, and green shales are the most common. The sands in Zone C<sub>1</sub> occur with gray, tan, and brown magnesian limestone and dolomite and commonly with a soft, bentonitic (?), green shale. In most of the wells the sand is free in the samples, but green shales studded with rounded sand grains are not uncommon. In Farnham Brothers' Lem Motlow No. 1 (10), in northern Moore County, and in W. F. Carter *et al.* Thomas Scantland No. 1 (22), in northern Jackson County,

<sup>34</sup> H. S. McQueen, *op. cit.*, pp. 122–23.

<sup>35</sup> R. P. Meacham, *op. cit.*, pp. 5–6.

considerable amounts of sand grains were imbedded in the dolomite.

The sandy zones, which occur in Zone C<sub>2</sub> are generally associated with dolomite and chert. The dolomite appears identical with that in the overlying Zone C<sub>1</sub>. The chert, however, exhibits considerable variation, which has been described in the discussion of Zone C<sub>2</sub>. In one well, the Basin Oil and Gas Company's Henry Harrell No. 1 (9), well rounded, relatively clear quartz grains were noted embedded in

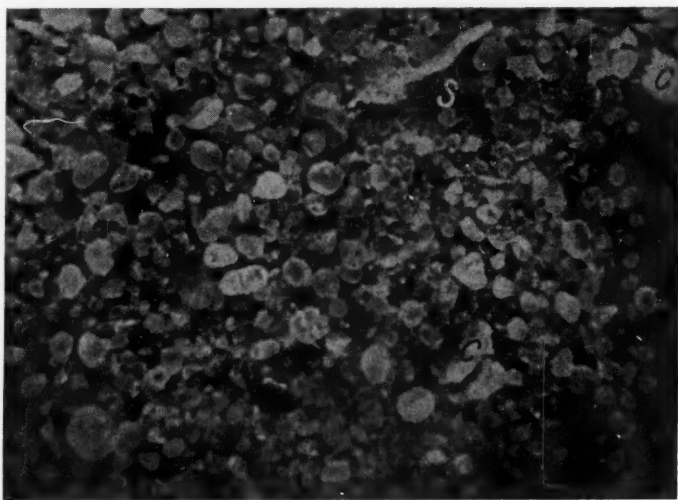


FIG. 7.—Subangular to well rounded, pitted and frosted quartz grains associated with typical Canadian green shale (S) and chert (C). Such zones have been referred previously to St. Peter sandstone. Depth, 1,275–85 feet, Farnham Brothers' Lem Motlow No. 1 (No. 10 in Figure 1). (X20.)

milky vitreous chert, similar to the type described by McQueen<sup>36</sup> in the Cotter formation in Missouri and by Ireland<sup>37</sup> in the second "Wilcox" sand in a well in east-central Oklahoma.

Minor minerals in these sandy horizons include minute fragments of limonite, sphalerite, pyrite, and marcasite. In a few wells very small amounts of fluorite, magnetite, and zircon have been noted.

*Correlation.*—There has been a tendency among drillers and operators in the southern Cincinnati arch region, especially in the shallow fields of the Upper Cumberland district in Tennessee and southern

<sup>36</sup> H. S. McQueen, *op. cit.*, p. 23 and Pl. VII B.

<sup>37</sup> H. A. Ireland, "Use of Insoluble Residues for Correlation in Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1926), pp. 1106–07.

Kentucky, to give the name "St. Peter sand" to any porous zone which occurs more than 500 feet below the base of the Pencil Cave marker. In all wells studied to date in middle Tennessee these sandy zones invariably occur below the top of Zone C<sub>1</sub>, definitely correlated with the upper part of the Knox dolomite group of Canadian age.

In the 30 sample sets studied these sandy zones do not occupy definite stratigraphic positions with reference to any subsurface datum plane, even in relatively close wells. Their sporadic occurrences are well shown in the cross sections in Figures 8 and 9. While the greater number occur in Zone C<sub>1</sub>, these sandy horizons range in depth from 15 feet below the top of this zone in the Wittmer Oil & Gas Company's J. J. Fuqua No. 1 (19) in central Jackson County to 205 feet in E. M. Ellis *et al.* Jim Higgins No. 1 (13) in central Cannon County.

Jillson<sup>38</sup> has recently correlated the producing zone in the Beech Bottom Oil and Gas Company's George Smith No. 1, drilled in 1922 in southeastern Clinton County, Kentucky, with the true St. Peter sandstone of the Mississippi Valley region. Small production was found in this test at 1,770-80 feet, about 850 feet below the base of the Pencil Cave marker. While the writer has not examined samples from this well, a complete sample set was studied from Jesse Ashby *et al.* Cinda Sells No. 1 (30), recently drilled in southeastern Pickett County, Tennessee, and approximately 6 miles south of the George Smith No. 1. The Sells No. 1 encountered the top of the Knox dolomite group at 1,540 feet, 772 feet below the base of the Pencil Cave. No sand was present above the Canadian in this test. Recent studies by Louise Barton Freeman<sup>39</sup> of the Geological Survey in the Kentucky Department of Mines and Minerals, point toward a Canadian age for the sandstone reported by Jillson as St. Peter in Wayne and Clinton counties, Kentucky.

The sandstone questionably correlated as St. Peter by Piper<sup>40</sup> at 610-20 feet in the Franklin Fuel and Oil Company's J. M. Alsop No. 1, just north of Murfreesboro in Rutherford County, is definitely below the top of the Knox dolomite group. The Basin Oil and Gas Company's Henry Harrell No. 1 (9), less than 2 miles removed, found very little sand at approximately this same stratigraphic position of the sandstone in the Alsop test.

Present studies, therefore, of these sandy pre-Stones River zones ("St. Peter") in middle Tennessee indicate: (1) though sandy zones do occur in the pre-Stones River rocks, no true quartz sandstones

<sup>38</sup> W. R. Jillson, *op. cit.*, pp. 24, 28.

<sup>39</sup> Louise Barton Freeman, written communication, May 27, 1939.

<sup>40</sup> A. M. Piper, *op. cit.*, pp. 60-61, 179.

LOWER ORDOVICIAN IN MIDDLE TENNESSEE 1661

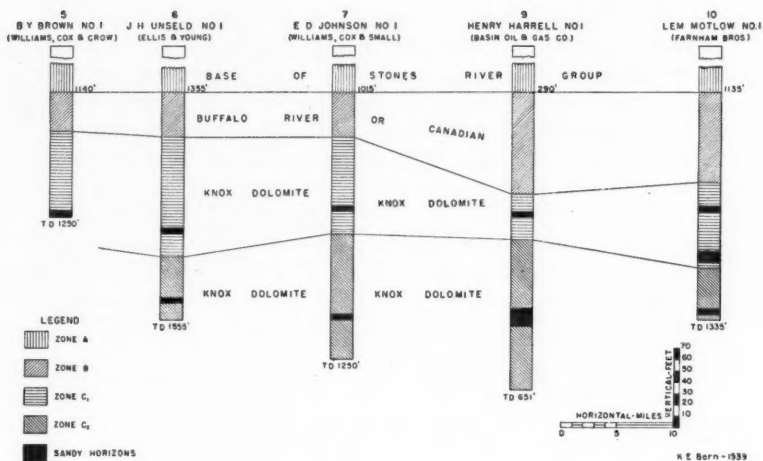


FIG. 8.—Cross section showing stratigraphic variability of pre-Stones River sandy zones across Nashville dome axis. Line of section is AA' in Figure 1.

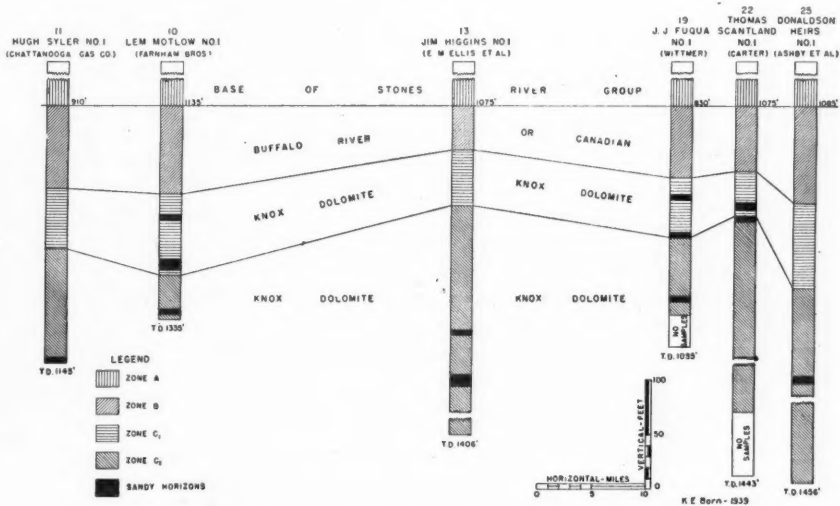


FIG. 9.—Cross section, approximately parallel with Nashville dome axis, showing stratigraphic variability of pre-Stones River sandy zones. Line of section is BB' in Figure 1.

have been found in sample examinations to date; (2) these sandy zones definitely occur in the upper part of the Knox dolomite group, which fixes a Canadian age for the "St. Peter" zone; and (3) these zones of porosity do not occupy a definite stratigraphic position with reference to established subsurface markers. The conclusion is forced, therefore, that the so-called "St. Peter sandstone" of middle Tennessee is a sporadic development of sandy zones in the upper part of the Knox dolomite group. It is interesting to note that such a correlation was suggested by Fanny Carter Edson<sup>41</sup> in 1935.

Since the continued use of the name "St. Peter" is both misleading and confusing, the writer<sup>42</sup> has recently recommended abandoning this name in the Upper Cumberland district.

<sup>41</sup> Fanny Carter Edson, "Résumé of St. Peter Stratigraphy," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), pp. 1,118-19.

<sup>42</sup> K. E. Born and H. B. Burwell, *op. cit.*, pp. 153-54.

NEW ZONE IN COOK MOUNTAIN FORMATION,  
THE *CRASSATELLA TEXALTA* HARRIS—  
*TURRITELLA CORTEZI* BOWLES ZONE<sup>1</sup>

H. B. STENZEL<sup>2</sup>

Austin, Texas

ABSTRACT

With the aid of persistent bentonite beds, it is feasible to trace and correlate a portion of the Cook Mountain formation in East Texas. The correlations possible are so detailed that individual beds can be recognized over a distance of more than 30 miles. These beds compose the Hurricane marine lentil of the lower Landrum member in the Cook Mountain formation.

The stratigraphic significance of this lentil is enhanced by the discovery of a new fossil zone. This zone is characterized by *Crassatella texalta* Harris and *Turritella cortezi* Bowles. This newly discovered zone is traceable beyond the confines of East Texas and allows correlation with corresponding portions in the Cook Mountain of the Rio Grande embayment and Louisiana.

Detailed stratigraphic correlations are very difficult to make in the Gulf Coastal Plain Eocene. Reasons for this difficulty are obvious. The general lack of clear and extensive exposures is one of the reasons. Another reason is the repetition of beds with similar composition in the stratigraphic column. One rarely knows whether one is tracing one and the same bed or some bed out of a set of beds occurring at slightly different levels in the stratigraphic column and composing a repetitional sequence of beds.

Therefore, it is surprising when one is able to find some beds that can be traced or correlated for a long distance and in extreme detail, that is, bed for bed. Such a set of beds is described in this paper. The stratigraphic importance of this set of beds lies not only in the fact that it can be traced bed for bed for a considerable distance but also that it is an important reference horizon useful for detailed structural definition and that it contains also a new and widespread paleontologic zone, significant in correlation.

The set of beds to be described occurs in the Cook Mountain formation<sup>3</sup> of East Texas. The East Texas Cook Mountain has been subdivided recently into several members which are defined by their composition.<sup>4</sup> These four members are as follows.

<sup>1</sup> Read before the Association at Chicago, April 12, 1940. Manuscript received, March 1, 1940. Published with the permission of E. H. Sellards, director, Bureau of Economic Geology, The University of Texas.

<sup>2</sup> Geologist, Bureau of Economic Geology, The University of Texas.

<sup>3</sup> In previous publications the writer used the name Crockett for this formation. The writer believes Cook Mountain to be preferable, because Cook Mountain is used in Louisiana and South Texas and thus has a more extensive usage.

<sup>4</sup> H. B. Stenzel, "The Geology of Leon County, Texas," *Univ. Texas Pub.* 3818 (1939), pp. 124-58.

Mount Tabor shale	} Cook Mountain (Crockett) formation
Spiller sand	
Landrum shale	
Wheelock marl	

The Wheelock member, at the base of the Cook Mountain, lies with a distinct disconformity on the underlying Stone City beds. The Wheelock consists chiefly of gray, calcareous, fossiliferous, glauconitic, marine shales. Impure limestones, highly glauconitic beds, and various concretions are common but subordinate. This member is 70 feet thick in Leon County, Texas. The type locality is Wheelock Prairie in Brazos and Robertson counties where 80 years ago the first Cook Mountain fossils of Texas were collected. These fossils were described by W. M. Gabb.<sup>5</sup> At the present time the best exposure of this member and the best collecting ground for fossils is on Little Brazos River in Brazos County, Texas.<sup>6</sup> The Wheelock member presumably changes partly by interfingering and partly by imperceptible transition into the overlying Landrum shale member. However, no clear exposures of the entire transition have been found so far so that the nature of the contact between the two members remains somewhat conjectural.

The lower part of the Landrum member consists of black-brown, unctuous, non-glauconitic or sparingly glauconitic shales of brackish-water or lagoonal origin. In these shale beds are some interbedded lentils of glauconites and of calcareous, glauconitic, marine shales. These lentils, however, are subordinate and compose only a small fraction of the total thickness of the Landrum shale. One of these marine lentils is important; it is the object of this study. Upward the Landrum shales become less unctuous, less plastic, and more silty. The black-brown and uniformly distributed color gives way to a speckled and lighter brown produced by lignitized plant remains. This upper part of the Landrum shale member is non-marine. The entire Landrum member is 110 feet thick in Leon County. At the top the Landrum shales become sandy and are interbedded with sand beds of increasing thickness. This transition and interfingering lead over to the next higher member, the Spiller sand. The type locality of the Landrum member is in southeastern Leon County on Two-Mile Creek,

<sup>5</sup> W. M. Gabb, "Descriptions of New Species of American Tertiary and Cretaceous Fossils," *Jour. Acad. Nat. Sci. Philadelphia*, Ser. 2, Vol. 4 (1860), pp. 375-406.

<sup>6</sup> Description of the location (Bureau of Economic Geology locality No. 21-T-1): on banks and in bed of Little Brazos River, from bridge of State Highway No. 21 upstream for about 0.3 mile; 9.43 miles west of courthouse in Bryan by speedometer; in southeastern part W. Mathis Survey, Brazos County. Best available topographic map: Brazos River (sheet 1), State Reclamation Department, Austin, Texas, advance sheet. For list of fossils, see B. C. Renick and H. B. Stenzel, "The Lower Claiborne on the Brazos River, Texas," *Univ. Texas Bull.* 3101 (1931), pp. 99-105, column 4.

which flows through the J. L. Landrum Survey. Excellent exposures are to be seen on the banks and along the tributaries of this creek.

The Spiller sand consists chiefly of gray or brown, lignitic sands with some brown shale partings. This member is non-marine and has a thickness of 105 feet in Leon County. The type locality is in southeastern Leon County near Spiller's Store.

Above the Spiller sand lies the Mount Tabor shale member which consists of brown, partly unctuous and partly calcareous shales. The shales contain subordinate beds of glauconitic marl and black, impure limestone, both rich in marine fossils. This member is partly marine, partly non-marine, but seems to be chiefly of brackish-water origin. The thickness is about 45 feet in Leon and Madison counties. The type locality is Mount Tabor School in northern Madison County. The Mount Tabor contains the stratigraphically highest marine fauna of lower Claiborne age in East Texas. The uppermost beds of the Mount Tabor contain in many localities a hard layer of glauconitic sandstone or calcareous clay-ironstone. This bed forms a prominent cuesta in many places. All beds above the Mount Tabor member are non-marine, although they combine to a thickness of 800-900 feet. These beds above the Mount Tabor member are in the Yegua formation.<sup>7</sup>

These four members of the Cook Mountain are not merely convenient local divisions, traceable and mappable as cartographic units in East Texas. They are traceable beyond the confines of East Texas eastward into Louisiana and westward at least to Colorado River in central Texas.

The Landrum member is easily traceable. Its brown, non-fossiliferous or sparingly fossiliferous shales contrast sharply with the underlying gray, fossiliferous, calcareous shales and marls of the Wheelock or with the sands of the overlying Spiller member. Even where no outcrops are found, the vividly colored, red-brown clay soil and steep cuesta front of the Landrum make it a readily distinguished, mappable unit with characteristic soils, topography, and vegetation. However, the various thin marine lentils contained in the Landrum shales were hitherto not traceable beyond a single outcrop. Where exposures are lacking these marine lentils are not shown by soil changes or topographic differences; these lentils are entirely lost in the Landrum shales wherever clear exposures are absent. Therefore, it has been

<sup>7</sup> H. B. Stenzel, "The Yegua problem," *Univ. Texas Pub.* 3945 (1939) [1940], pp. 847-904.

E. A. Wendlandt, associate editor of this *Bulletin*, states that although essentially the Yegua is non-marine, rather recently a fossiliferous zone in beds of unquestionable Yegua age was found in Fayette County.

SW

# THE HURRICANE LENTIL IN LEON AND

BY H.B. STENZEL -

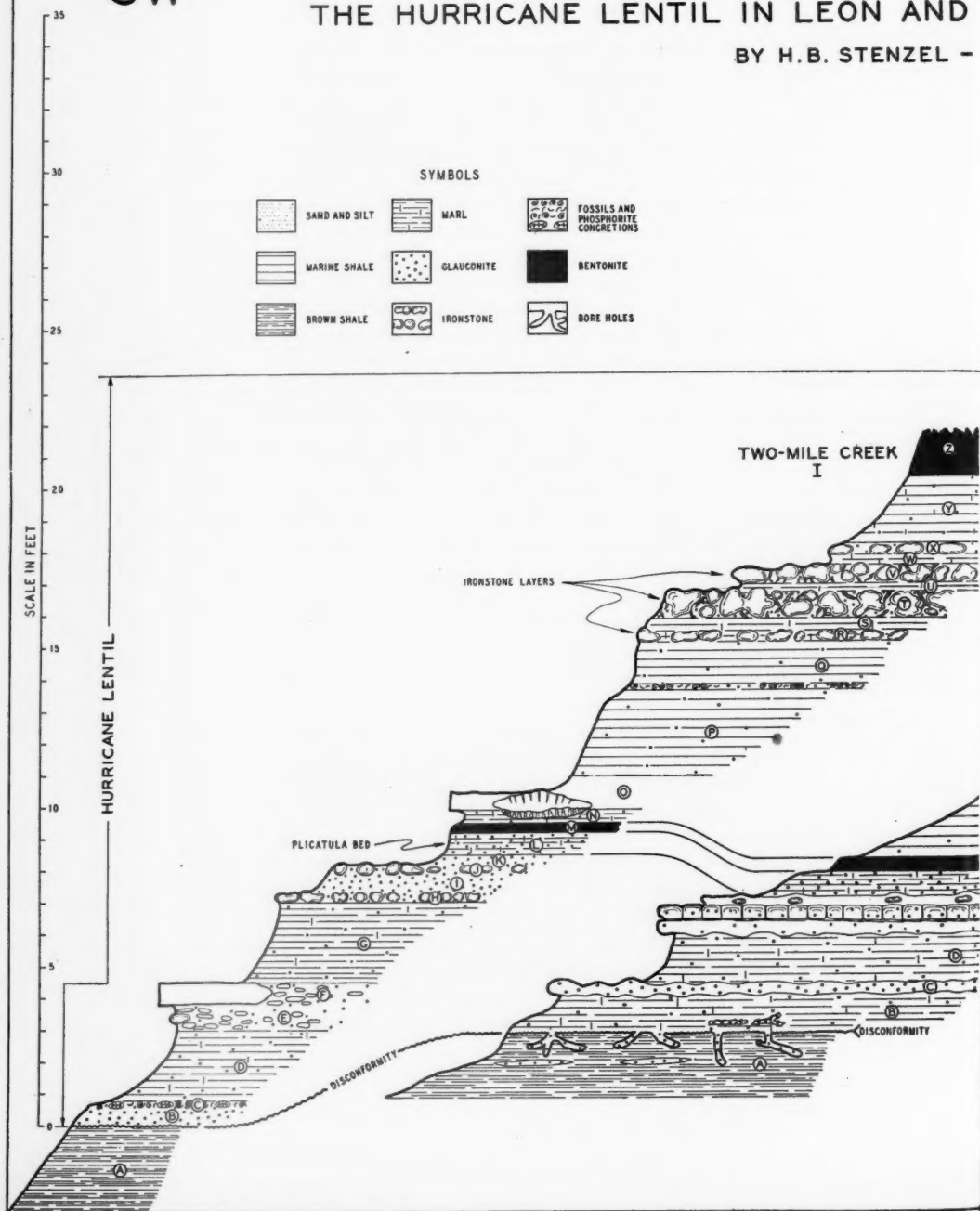


FIG. 1.—Hurricane lentil in Leon

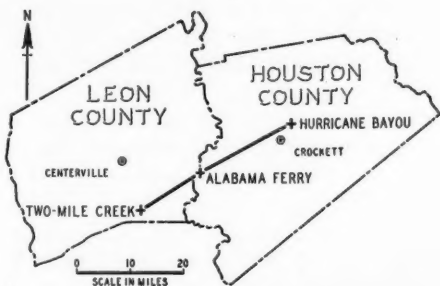
ND  
EL -

# HOUSTON COUNTIES, TEXAS

1940

ALABAMA FERRY  
II

NE



HURRICANE BAYOU  
III

UPPER BENTONITE

SILT

LOWER BENTONITE

PLICATULA BED

and Houston counties, Texas.

hitherto impossible to trace any one of these lentils from one isolated exposure to another. In mapping from one isolated exposure to the next one, one could never be certain whether one was dealing with one and the same lentil or two lentils at slightly different stratigraphic levels.

Recently this difficulty has been overcome at least for one of these marine lentils in the lower Landrum shale member. At the same time it has become apparent that this lentil is of particular stratigraphic importance because it contains a newly recognized fossil zone in the Cook Mountain formation.

During the mapping of Houston County in East Texas the writer has been particularly interested in the occurrence of bentonite beds. High-quality bentonite of commercial value has been found in some Cook Mountain exposures. Continued investigation has shown that these bentonite occurrences are in marine lentils of the Landrum member. Then, on comparing the different sections it has been found that these bentonites are continuous and with their aid the sections can be correlated bed for bed (Fig. 1). There are two bentonite beds, the lower one only 0.3-0.4 of a foot thick and the upper one 3.3-3.6 feet thick. The stratigraphic interval between these two beds is 9.7-10.9 feet. It is easy to see that with the aid of these two bentonite beds, sections can be readily compared and correlated because one can use the thicknesses of the bentonites and the interval between them for checking—a method that furnishes three separate checks for stratigraphic correlation. In addition, certain prominent clay-ironstone ledges are recognizable in these exposures. These ledges occupy not only similar stratigraphic positions but are also of more or less constant character. Of particular interest is the uppermost clay-ironstone ledge which is composed of three crowded concretionary layers in all sections (beds *t*, *u*, and *v* of section I, beds *m* and *l* of section II, and bed *k* of section III). Even such minor compositional features as the thin silt layers (beds *j* of section II and *i* of section III) are traceable from one section to the other.

The fauna of the beds also adds some checks for their correlation. At one level, immediately below the lower bentonite, the small pelecypod *Plicatula* is very abundant. This *Plicatula* layer is present in all three sections. The large pelecypod *Crassatella texalta* Harris and the curious gastropod *Turritella cortezi* Bowles occur in the marine lentil of these localities. These fossils are particularly important because they are not found in the remainder of the Cook Mountain formation.

The detailed correlation of the three sections bed for bed is therefore based on the following stratigraphic checks.

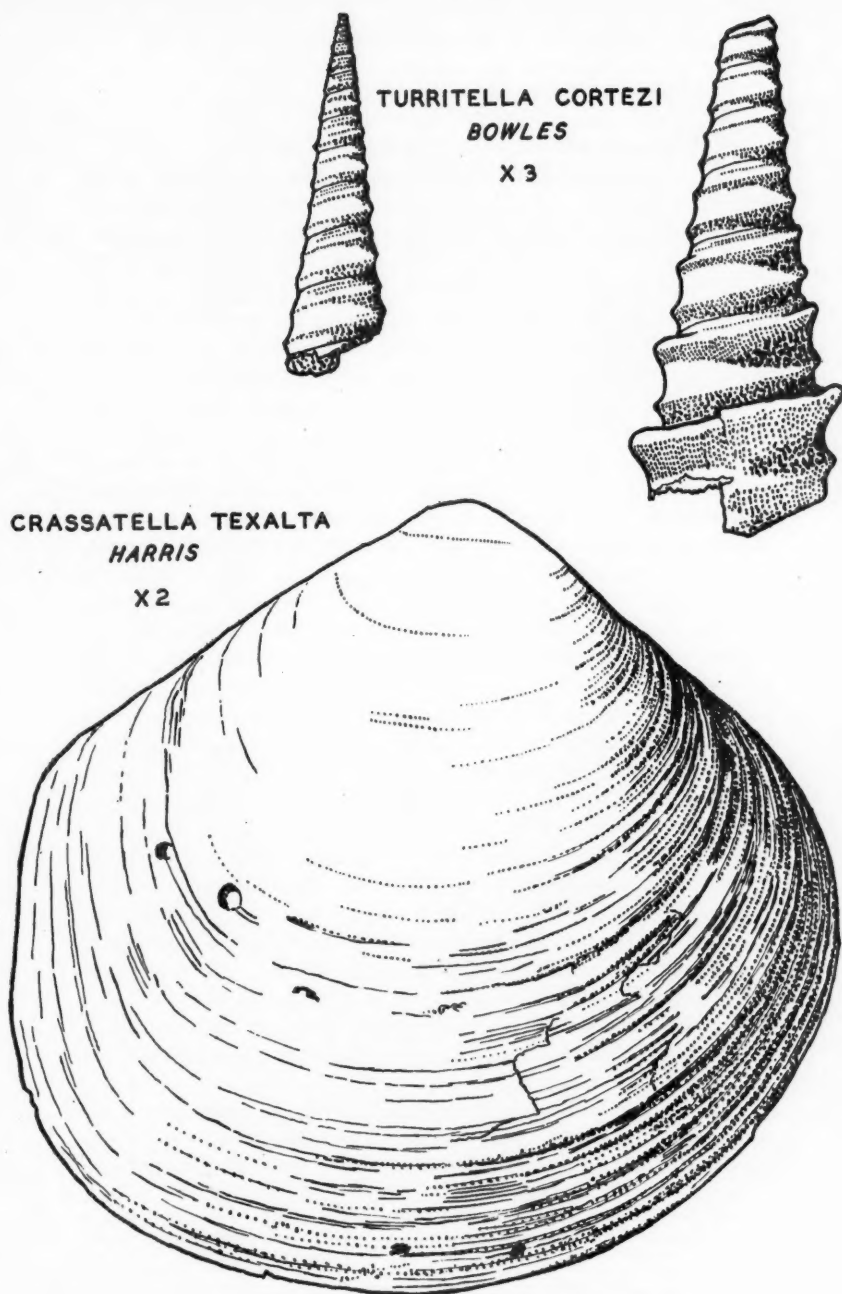


FIG. 2.—Guide fossils of Hurricane lentil.

Bentonite (two beds and distance between them)

Clay-ironstone ledges (character and position)

*Plicatula* bed

Zone of *Crassatella texalta* Harris and *Turritella cortezi* Bowles

Such a combination of checks in so small a stratigraphic range makes it absolutely certain that in this case it is one and the same marine lentil that is exposed in the Landrum shales at the three separate localities in Leon and Houston counties. For this marine lentil the name Hurricane lentil is herewith proposed. The Hurricane lentil and in particular its bentonite beds can be used for detailed structural definition in this region. With the aid of auger holes or bore holes the bentonite beds could be traced and used for structural work.

However, the importance of the Hurricane lentil lies in its fossil content. As pointed out, *Crassatella texalta* Harris and *Turritella cortezi* Bowles occur in this lentil. These two fossils are not known from any other level in the Cook Mountain formation of East Texas. *Crassatella texalta* Harris is replaced above and below its occurrence in the marine Hurricane lentil by a related but easily differentiated species, *Crassatella antestriata* Gabb. The latter species is common in nearly all Cook Mountain exposures of East Texas, but it is absent in layers which contain *Crassatella texalta* Harris. *Turritella cortezi* Bowles is replaced above and below its occurrence in the marine Hurricane lentil by several species of *Turritella*, such as *T. dulcexata* Harris, *T. nasuta* Gabb, and *T. nasuta brazila* Stenzel and Turner. However, some of these species occur also with *Turritella cortezi* Bowles. An additional species of *Turritella* which occurs with *T. cortezi* Bowles is *T. houstonia* Harris. In the Cook Mountain formation *Turritella houstonia* Harris is restricted to this marine lentil of the Landrum member, but the species is a facies fossil rather than a guide fossil. It occurs ordinarily in marine beds intercalated between brown, non-fossiliferous or sparingly fossiliferous shales. It is also found in similar facies in the Stone City beds. There are other less conspicuous species of fossils restricted to this marine lentil. However, it seems premature at this stage of the investigation to enumerate all fossils or to give lists of fossils. It is sufficient to know that this marine lentil of the Landrum shales carries a distinctive fauna which is restricted to this stratigraphic level of the Cook Mountain formation.

The recognition of this stratigraphic level and its characteristic fossil content in East Texas is of importance to long-range correlation. At the time this zone was recognized by the writer,<sup>8</sup> its zone fossils

<sup>8</sup> The writer recognized this new fossil zone in 1934. H. B. Stenzel, "The Geology of Leon County, Texas," *Univ. Texas Pub.* 3818 (1939) [issued June 30, 1939], pp. 157-58. In this report *Turritella* n. sp. aff. *subrina* Palmer is *Turritella cortezi* Bowles. Bowles described this species. Edgar Bowles, "Eocene and Paleocene Turritellidae of the Atlantic and Gulf Coastal Plain of North America," *Jour. Pal.*, Vol. 13 (1939) [issued May, 1939] pp. 280-81.

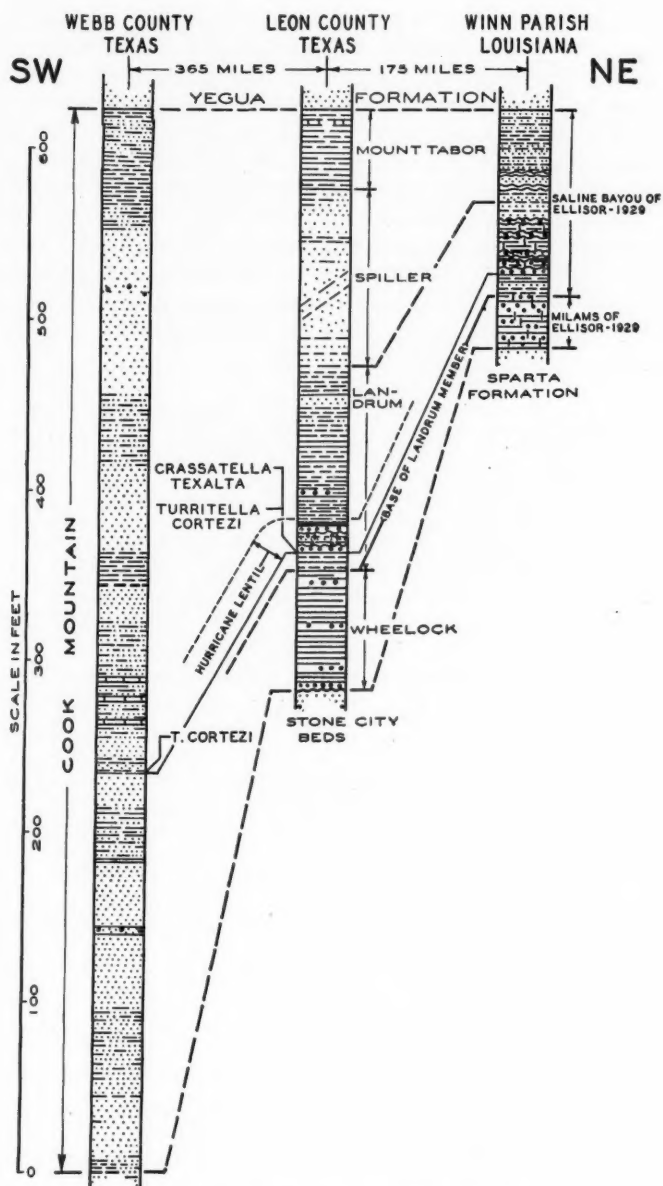


FIG. 3.—Correlation of Cook Mountain formation.

were not known outside of East Texas. However, recently *Turritella cortesi* Bowles has been described from Mexico, and its occurrence in a definite stratigraphic level of the Cook Mountain formation of Mexico and adjoining portion of Texas has been pointed out. Bowles described *T. cortesi* from a locality 7,200 meters S. 44° W. from the church tower in Mier, Tamaulipas, Mexico, and stated that it occurs at a definite level in the Cook Mountain formation of Webb County. Therefore, it is now possible to correlate the marine lenticle in the lower Landrum of Houston and Leon counties with the beds bearing *Turritella cortesi* Bowles in the Rio Grande region. The almost simultaneous discovery of this fossil zone in two separate regions is highly fortunate because it has established at once the stratigraphic importance of this zone.

DESCRIPTION OF THREE SECTIONS OF THE LOWER LANDRUM  
MEMBER EXPOSED IN LEON AND HOUSTON COUNTIES,  
TEXAS (COMPARE FIG. 1)

I. Two-Mile Creek, Leon County, Texas. Exposures along creek banks beginning at iron bridge of Leona—Two-Mile School county road, 4 miles southeast of Leona, airline distance, and extending up creek to sharp meander in creek about  $\frac{1}{2}$  mile from iron bridge; Bureau of Economic Geology localities Nos. 145-T-52, 145-T-71, 145-T-combined in one section.

SECTION ALONG TWO-MILE CREEK

	Thickness Feet
z. Bentonite, dark green when fresh, bright green when weathered, waxy, conchoidally fracturing; top part cut off by terrace deposits. ....	1.4+
y. Gray-greenish brown on surface, soft, thin-bedded, richly fossiliferous, glauconitic marl; lower part dark brown on fresh pieces and full of delicate thin-shelled fossils; upper part light gray-green on fresh pieces and poorer in glauconite; <i>Harpectocarinus americanus</i> Rathbun and cypræid found here. ....	2.1
x. Row of red-brown, ellipsoidal concretions of 0.3-foot thickness and with cores of fresh, gray-greenish blue, dense, fossiliferous, glauconitic limestone. ....	0.3
w. Gray-greenish brown on surface, soft, thin-bedded, fossiliferous, glauconitic marl; fresh pieces are as lower part of bed y. ....	0.3
v. Bench of brown and yellow, rough, nodular clay-ironstone concretions surrounded by light gray-green, glauconitic limestone which has irregular network of calcite veins. ....	0.6
u. Gray-greenish brown, soft, thin-bedded, fossiliferous, glauconitic marl similar to bed w. ....	0.3
t. Bench, like bed v. ....	0.8
s. Marl, like bed u. ....	0.4
r. Row of red-brown concretions like bed x. ....	0.3
q. Light gray-green to blue, glauconite-poor marl similar to lower part of bed y. ....	1.4
Discontinuous layer of richly fossiliferous glauconite marl. ....	0.1
p. Dark greenish brown, thin-bedded, glauconitic marl; contains many <i>Anomia lisbonensis</i> Aldrich. ....	2.7

- o. Discontinuous, light yellow, hard limestone composed of cores, envelope, and cone-in-cone layers; cores are separate, flat, ellipsoidal, shrinkage-cracked, and partly healed limestone concretions 2.3, 4.2, 4.3, and 7.2 feet in diameter and 0.4-0.5 foot in thickness; their cracks or net-like calcite veins show on weathered surfaces; envelope is of smooth, continuous, not cracked limestone; cone-in-cone layers occur under cores only; limestone of cores and envelope is gray to greenish blue, dense, and a little glauconitic when fresh. . . . . 0.0 to 1.1
- n. Light chocolate-brown, fossiliferous, glauconite-poor marl. . . . . 0.4
- m. Intensely green on fresh break, soapy bentonite with numerous slippage planes. . . . . 0.3
- l. Light greenish gray to bluish gray, fossiliferous marl with little irregularly distributed glauconite and numerous 2-valved *Plicatulas*. . . . . 0.7
- k. Olive-colored, poorly bedded, richly glauconitic and fossiliferous marl with *Harporocarcinus americanus* Rathbun. . . . . 0.3
- j. Scattered knobs of red-brown clay-ironstone weathered from dense, bluish, glauconitic limestone of 0.3-0.8 foot horizontal diameter. . . . . 0.3
- i. Same as bed *k*; contains silicified log with shipworm borings; small anterior vertebra of *Protocetus* sp. Remington Kellogg,\* an early whale, found here. . . . . 0.6
- h. Similar to bed *j* but knobs are larger and more crowded; average horizontal diameter is 0.5 foot; this bed makes riffles in water and is utilized for ford; this layer is thicker and more continuous on left bank about 50 feet upstream from ford where it is 0.7 foot thick. . . . . 0.3
- g. Green-brown, weathered, thin-bedded, fossiliferous, glauconitic marl with some limestone nodules; thickness of 2.5 feet is not exposed at ford but represents entire thickness of bed; it was measured at mouth of a small, winding tributary about 100 feet above ford. . . . . 2.5
- f. Brown-yellow, hard, very impure limestone, discontinuous and partly replaced by bed *e*. . . . . 0.6 to 0.8
- e. Brown and yellow, irregular, concretionary limestone nodules. . . . . 0.8
- d. Dark green-brown, thin and poorly bedded, glauconitic, fossiliferous marl. . . . . 2.2
- c. Slightly indurated shell and concretion layer with some black, cracked phosphorite concretions. . . . . 0.2
- b. Brown-green, massive to poorly bedded, fossiliferous, glauconitic marl. . . . . 0.6
- Sharp boundary, base of marine lentil.
- a. Chocolate-brown, laminated to thin-bedded, lignitic shales with yellow efflorescences of copiapite; total thickness not exposed, to water level. . . . . 2.7

\* Remington Kellogg, "A Review of the Archæoceti," *Carnegie Inst. Washington Pub.* 482 (1936), pp. 242-43, Pl. 15, Figs. 4-6.

II. Alabama Ferry, Houston County, Texas. Left bank of Trinity River about 0.2-0.5 mile downstream from the abandoned Alabama Ferry, about 7.5 miles west-southwest of Porter Springs; Bureau of Economic Geology locality No. 113-T-9.

Exposures on left bank of river, beginning 600 feet below ferry, and extending 2,000 feet downstream. Dip is downstream so that older beds are visible on upstream end and younger beds on downstream end of bluffs. Mouth of small creek divides exposures into two parts. Upstream part has beds *a* to *m* visible; downstream part has beds *j* to *n* showing. Therefore, upstream part is predominantly marine and richly fossiliferous; downstream part is predominantly brown shale and poor in fossils.

## SECTION AT ALABAMA FERRY ON LEFT BANK OF TRINITY RIVER

	Thickness Feet
t. Brown shale, similar to bed <i>g</i> but more weathered.....	2.5
s. Brown shale with four light-colored silty shale beds, which are about 0.1-0.2 foot thick.....	3.8
r. Clay-ironstone concretions, hard, yellow-brown, smooth-surfaced, discontinuous, in many cases with shell layer through middle...	0.3
q. Brown shale, black-brown when fresh, chocolate-brown when weathered, thin-bedded, gypsiferous, nearly everywhere devoid of fossils.....	7.1
p. Shale, gray-brown, waxy, bentonitic, thin and well bedded, with few fossils but no glauconite.....	2.0
o. Bentonite, bright green when weathered, black-green when fresh, waxy, with many desiccation cracks; this bed forms broad, flat bench at low-water stage on south end of exposure.....	3.6
n. Glauconite marl, as bed <i>l</i> ; this bed contains here and there 3-inch layer of clay-ironstone in south part of exposure.....	0.8
m. Clay-ironstone bench, hard, brown, glauconitic, fossiliferous, roughly arranged in two layers separated by marl seam.....	0.9
l. Glauconite marl, gray-green, massive, rich in fossils, with basal 2-inch thick shell breccia at one place; contains here and there clay-ironstone concretions.....	1.9
k. Marl, as bed <i>i</i> .....	0.8
j. Silt beds, light gray, muscovitic, well bedded, paper-thin in most places, but at one place 3-inch thick bed occurs; separated by silty marl similar to bed <i>i</i> .....	0.8
i. Marl, gray-blue to gray-green, poor in glauconite and fossils.....	4.5
h. Bentonite, gray-blue when fresh, bright green when weathered, waxy, with many slippage planes.....	0.4±
g. Glauconite marl, gray-green, soft, richly fossiliferous; abounds in <i>Plicatula</i> ; contains <i>Crassatella texalta</i> Harris.....	0.8
f. Limestone, hard, gray-green, glauconitic, fossiliferous, marly, encloses balls of brown clay-ironstone.....	0.3
e. Clay-ironstone bench, hard, brown, irregular, richly glauconitic, fossiliferous, similar to bed <i>c</i> , in most places in two separate layers; makes most extensive bench of outcrop.....	0.9
d. Glauconite marl, similar to bed <i>b</i> but slightly lighter in color; contains <i>Crassatella texalta</i> Harris and <i>Turritella cortezi</i> Bowles; base of this bed contains clay-ironstone layer but only at downstream end.....	1.5
c. Clay-ironstone bench, hard, brown, irregular, fossiliferous, richly glauconitic; one <i>Crassatella texalta</i> Harris was found in top of this bed.....	0.4
b. Glauconite marl, dark green, fossiliferous; broken coral branches are common in base of this bed and branching pipes filled with material from this bed extend into bed <i>a</i> .....	1.2
<hr/> <i>Disconformity</i> <hr/>	
a. Shale, black to black-gray, non-fossiliferous, non-glauconitic, with dark gray, muscovitic silt partings and a few lenses of glauconite marl in upper part.....	2.0+

# NEW ZONE IN COOK MOUNTAIN FORMATION 1675

III. Hurricane Bayou, Houston County, Texas. Bed of creek 0.2-0.5 mile up creek from bridge on Crockett-Rusk county road (mail route 1), 3.35 miles northeast of Crockett; Bureau of Economic Geology locality No. 113-T-2.

Outcrops at this long-known locality occur on two meanders of creek. As apparent dip is downstream, upper beds, that is, beds *e* to *n*, crop out in lower meander, whereas lower beds, that is, beds *a* to *f*, crop out in upper meander. Following section is composed of all beds visible in the two places.

## SECTION AT HURRICANE BAYOU

	Thickness Feet
n. Brown shale, badly weathered to red-brown clay soil. ....	—
m. Bentonite, dark green, waxy, conchoidally fracturing, pure, with numerous desiccation cracks. ....	3.3±
l. Marl, slate-gray, thin-bedded, poor in fossils and glauconite. ....	0.5
k. Clay-ironstone concretions in marl; hard, yellow, brown, or purple, concentric concretion heads arranged roughly in three layers of which uppermost is more brightly yellow in color; marl is dark green and rich in glauconite and fossils. ....	3.2
j. Marl, same as bed <i>h</i> . ....	0.8
i. Silt lentils, light gray-yellow when weathered, well bedded, muscovitic, lacking fossils and glauconite. ....	0.4
h. Marl, light gray to light greenish brown, thin-bedded, unctuous, slightly glauconitic and fossiliferous. ....	6.0
g. Bentonite, dark green-black, with numerous slippage planes and irregular pockets of fossils and glauconite. ....	0.3
f. Marl, dark green, richly fossiliferous and glauconitic, with several nonpersistent 1-inch thick layers of brown clay-ironstone; particularly rich in <i>Plicatulas</i> ; <i>Crassatella texalta</i> Harris occurs in this bed. ....	1.5
e. Clay-ironstone bed; this bed forms flat creek bottom at north end of lower meander, where it is a hard, dull maroon-colored, uneven, richly glauconitic and fossiliferous bed. This bed is much better exposed in creek bottom of upper meander but consists there of weathered and indurated, brown, glauconitic fucoidal, impure clay-ironstone. ....	
d. Clay-ironstone, hard, yellow-brown, glauconitic, calcareous; its surface thrown into large shell-ridge ripple marks which trend N. 20° E. and are as an average 4 feet apart. Beds <i>d</i> and <i>e</i> . ....	0.8
c. Marl, weathered, glauconitic, but not indurated. ....	0.8
b. Limestone, hard, brown, weathered, impure, smooth-topped. ....	0.5
a. Marl, same as bed <i>c</i> . ....	0.5+

Beds *a* to *c* are exposed around deep waterhole at sharp right-hand turn upstream from upper meander

## GEOLOGICAL NOTES

### COAL IN EOCENE, NEAR BAKERSFIELD, CALIFORNIA<sup>1</sup>

ROBERT W. CLARK<sup>2</sup>  
Los Angeles, California

Eocene coal has been known in California for a long time and there have even been some mining operations carried on.<sup>3</sup> The localities cited are on the east side of the northern Sacramento Valley and on the west side of the San Joaquin Valley in the coast ranges. No Eocene coal has been mentioned on the east side of the San Joaquin Valley. In fact there is no published information on the Eocene in the east side of the southern half of the valley since it does not crop out there and only a few wells have penetrated it. Therefore the finding of Eocene coal in the Western Gulf Oil Company's KCL-B No. 45, in Sec. 22, T. 29 S., R. 27 E., in the Fruitvale field, seems worthy of comment.

The Rio Bravo sand was encountered at 8,920 feet. A 15-foot shale interval separated this sand from true Vedder. Brown shale was encountered at 9,240 feet. A core, spotted at 9,420-9,430 feet, contained *Siphogenerina nodifera*. The lower 300 feet of this shale was sandy for the most part but at 9,900 feet the formation became coarse sandstone. From fossil and lithologic evidence the Tumey shale and Tumey sand (Kreyenhagen) occupy the interval from 9,240 to 9,900 feet. There is no direct fossil evidence from the sand below 9,900 feet, but from the sequence and by comparison with other known areas it is assumed to be Eocene in age. This sand with some minor shale breaks and shaly facies extends down to 10,500 feet. Basement rocks were encountered at 10,588 feet, the overlying 88 feet being a vari-colored claystone.

The coal occurs in the Eocene sand body at approximately 10,300 feet. Since the core recovery in this interval was reported to be 100

<sup>1</sup> Manuscript received, July 12, 1940.

<sup>2</sup> Chief geologist, Western Gulf Oil Company.

<sup>3</sup> Charles A. Anderson and R. Dana Russell, "Tertiary Formations of Northern Sacramento Valley, California," *California Jour. Mines and Geology*, Vol. 35, No. 3, pp. 230 and 251.

Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District, California," *U.S. Geol. Survey Bull.* 308 (1910), p. 49.

Robert Anderson and Robert W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley North of Coalinga, California," *U.S. Geol. Survey Bull.* 603 (1915), pp. 67, 70, 72, and 209.

James Perrin Smith, "The Geologic Formations of California," *California State Min. Bur. Bull.* 72, p. 16.

per cent, the section may be described as follows, beginning at 10,295 and proceeding downward.

	Thickness Feet Inches		Depth in Feet
White, floury, medium-grained sand	2		10,295
Coal	4		
Very dark sandy siltstone	1		
Coal	3		
Glauconitic well sorted sand	2	6	
Coal	0	6	
Sand, as above	1		
Sand cemented with pink clay	7	6	
Claystone, gritty	0	3	
Coal	0	6	
Claystone	0	3	
Glauconitic sandstone	1	6	10,320

The main coal seam is an 8-foot bed with a 1-foot bone about in the middle of it. No clay was apparent either above or below the coal, except the lowest bed. The coal is black with a near-pitchy lustre, subconchoidal fracture and brownish streak. Proximate analyses<sup>4</sup> of two samples, A. 10,297-10,301 and B. 10,302-10,305, gave the following results.

	A Original Moisture and Ash-Free Basis		B Original Moisture and Ash-Free Basis	
Moisture	2.715		2.725	
Ash	15.02		12.34	
Volatile matter	47.585	57.84	50.725	59.72
Fixed carbon	34.68	42.16	34.21	40.28

The moisture content will have to be disregarded in classifying this coal since the cores stood unprotected several days before the analyses were made. Then they were washed to remove drilling mud and then air-dried for 24 hours. The low percentage of fixed carbon and high percentage of volatile matter would make this coal appear to be lignite. However, Campbell<sup>5</sup> says:

The term "lignite," as used by the Geological Survey, is restricted to those coals which are distinctly brown and either markedly woody or claylike in their appearance. The term "subbituminous" is adopted by the Geological Survey for what has generally been called "black lignite." . . . Subbituminous coal is generally distinguishable from lignite by its black color and its apparent freedom from distinctly woody texture and structure. . . .

This coal, then, should be ranked as *subbituminous*. Campbell<sup>6</sup> shows an analysis of a subbituminous coal from the Tesla district, Cali-

<sup>4</sup> Made by the Gulf Research and Development Corporation, Pittsburgh, Pennsylvania.

<sup>5</sup> Marius R. Campbell, "The Coal Fields of the United States," *U.S. Geol. Survey Prof. Paper 100-A* (June, 1917), p. 7.

<sup>6</sup> *Op. cit.*

fornia, with a fixed carbon content of about 40 per cent on a water- and ash-free basis, and one from Mt. Diablo with 46 per cent, which agrees with the present classification.

Two other wells have been drilled to the basement in the Fruitvale area and did not encounter the coal. These are the Meridian Oil Company's Fee No. 2, about 6,000 feet northeast of the Western

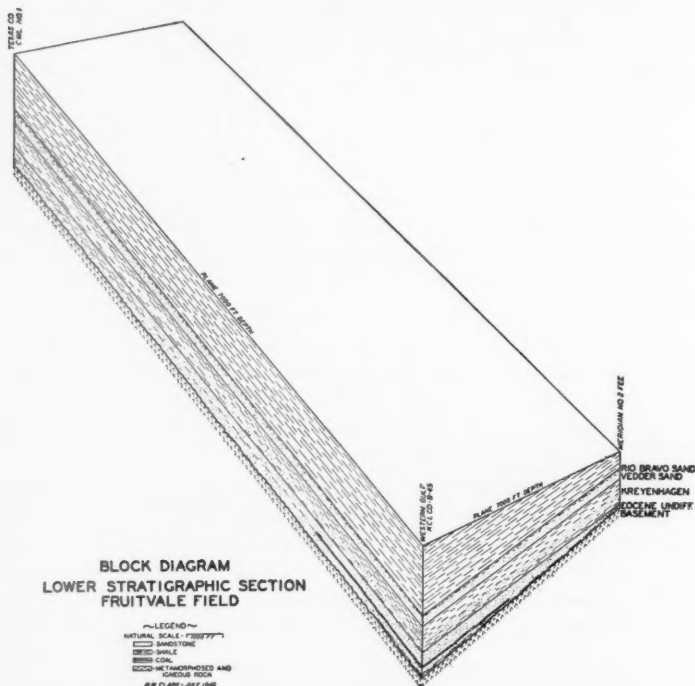


FIG. 1

Gulf well, in Section 23, and The Texas Company's Camp-West-Lowe No. 1, a little more than 3 miles northwest, in Section 7. The block diagram shows the stratigraphic relationships of the lower part of the section down to the basement in these three wells. This is not a true perspective since it is desirable to show true thicknesses at the three wells. At the time the coal material was being accumulated in the bogs and coastal lagoons at the location of No. 45, the Meridian site was still high and dry, while the Camp-West-Lowe site was out in the sea far enough to be receiving mud and silt deposits. The

lagunal area must have been a very narrow strip, trending nearly north or slightly west of north. The site of the two Shell Oil Company wells near Famosa, about 15 miles N. 30° W. of Fruitvale, appears to have been deeper water at the coal-forming period. The length of the lagunal area is not even suggested because of lack of drill holes.

The writer's thanks are due K. C. Heald, of the Gulf Oil Corporation, Pittsburgh, Pennsylvania, for criticism and permission to publish this note; also R. C. Barker, of the Gulf Research and Development Corporation, for the analyses, and P. M. Jameson for the drafting.

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PROBABLE LOWER MISSISSIPPIAN AGE OF THE  
CABALLOS NOVACULITE, NEW MEXICO<sup>1</sup>

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College Station, Texas

The basal conglomerate of the Pennsylvanian Magdalena group in the northern San Andres Mountains, from Sheep Mountain northward, in south-central New Mexico, is composed of angular boulders of vari-colored, but mostly white, novaculite. Extensive search led to the discovery, in the southern anticlinal nose of Fairview Mountain, T. 10 S., R. 4 E., of novaculite in place, directly beneath the unconformity at the base of the Magdalena.

The novaculite rests here on a medium-bedded dense fine-textured blue-gray limestone which is the basal bed of the Lake Valley Mississippian lying unconformably on fossiliferous Upper Devonian clayey sandstones and sands. The basal Mississippian limestone contains lenses of novaculite in its upper part. The novaculite occurs in large concretionary-like "pillows" free from the admixture of any other kind of rock and banded in the various colors found in the Caballos novaculite, white and light green predominating. In places a very deep brown-red shale is found overlying the novaculite both above and below the unconformity at the base of the Magdalena. Exactly similar shale, evidently a weathering product, is found on the unconformable contact of the Tesnus and Caballos novaculite at various places in the Marathon basin, trans-Pecos Texas.

The basal conglomerate of the Magdalena in the northern San Andres Mountains is practically entirely angular boulders of novaculite varying up to 3 feet in diameter. This conglomerate ranges from 1 foot to 6 feet in thickness.

<sup>1</sup> Manuscript received, July 29, 1940.

<sup>2</sup> Department of geology, Agricultural and Mechanical College of Texas.

Further stratigraphic details pertinent to the subject will be given. All pre-Magdalena formations thin from south to north in the San Andres Mountains as they approach the "Colorado Island," a pre-Pennsylvanian land mass. All the Paleozoic formations are well delimited by basal unconformities and are easily distinguishable lithologically as well as faunally. The following table gives the thickness of these formations in the southern and northern parts of the range.

PALEOZOIC FORMATIONS IN SAN ANDRES MOUNTAINS, NEW MEXICO  
(Thickness in Feet)

	<i>Southern</i> (Ash Canyon)	<i>Northern</i>
Magdalena	4,300	
Lake Valley	315	5-75
Upper Devonian	165	10-70
Fusselman dolomite	450	Absent
Montoya dolomite-limestone	645	110
El Paso limestone	138	80
Bliss sandstone	115	0-7

The Upper Devonian and the Lake Valley thin from south to north at the northern end of the range. The basal bed of the Lake Valley is a limestone with an underlying surface of irregularity, resting on a section of the Upper Devonian which thins from south to north. Fossils are more numerous in the upper part of the Devonian section. In the Ash Canyon section of the southern San Andres Mountains the lower third of the Devonian is black fissile shale and the upper two-thirds mainly hard concretionary, poorly laminated calcareous mudstones with fossils. This is rather typical Percha shale. The lithology of the Devonian is markedly different in the northern part of the range, the strata being predominantly sandy and pebbly although some brown laminated sandy shale occurs in the lower half on the south side of Sheep Mountain.

The following section, in descending order, of Lake Valley occurs on the north wall of Sly Gap Canyon on the southern slope of Sheep Mountain.

LAKE VALLEY FORMATION, SLY GAP CANYON, SHEEP MOUNTAIN, NEW MEXICO

	<i>Thickness</i> <i>in Feet</i>
1. Basal Magdalena conglomerate of novaculite boulders	1-6
2. Novaculite, nodular, with nodules coated dark green	8
3. Limestone, heavy-bedded, blue-gray, with novaculite lenses	15
4. Fossiliferous clayey blue-gray limestone grading down into coarsely laminated blue-gray clay	20
5. Limestone, medium-bedded, dense blue-gray, with dark chert lenticles in upper 18-20 feet. Contains diorite-porphphy sill 8 feet thick, 5 feet below top, and rests on eroded surface of poorly indurated fine-grained, light brown clayey and fossiliferous sandstone of Upper Devonian	23
In places here members (2) and (3) are missing	

Well preserved diagnostic fossils were collected from Devonian and Mississippian in various of the northern exposures.

There is considerable probability from the foregoing that part or perhaps all of the Caballos novaculite is the correlative of the former upper part of the lower Mississippian section of southern New Mexico in which now only remnants of the novaculite have been preserved from the erosion taking place previous to deposition of the Magdalena group.

## DISCUSSION

### POSSIBILITIES OF HEAVY-MINERAL CORRELATION OF SOME PERMIAN SEDIMENTARY ROCKS, NEW SOUTH WALES, BY DOROTHY CARROLL

DISCUSSION BY H. G. RAGGATT<sup>1</sup> AND IRENE CRESPIN<sup>1</sup>  
Canberra, A.C.T., Australia

In the April number of this *Bulletin* (Vol. 24, No. 4 (April, 1940), pp. 636-48), Dorothy Carroll discussed the correlation value of heavy-mineral assemblages of some of the sediments exposed and proved by drilling in the central-eastern Permian basin of New South Wales. (All place and formation names mentioned in this note are included in Dr. Carroll's paper.)

Dr. Carroll is an experienced worker, and with most of her comments we agree. However, after stressing the difficulties of reaching definite conclusions based on examination of a limited number of specimens, and pointing out that lateral (facies) differences may be greater than vertical ones, she states: "Taking all the available information, the lithology, the heavy-mineral suites, the grain-size, and the presence of brachiopods, it seems valid to conclude that the Kulnura grit is part of the upper Marine series, probably the Murree stage." There are two lines of evidence which show that it is highly improbable that this "Kulnura grit" cored at 6,293 feet can be correlated with the Murree beds.

One is, that it is entirely opposed to the trend of paleogeographic evidence, the other that it is opposed to the lithological and paleontological evidence as revealed by a detailed study of the bore log. The first line of evidence will be discussed elsewhere by one of us (H.G.R.) in the near future, the second is briefly presented here.

The drill cuttings from the Kulnura bore were critically examined by one of us (I.C.) whilst drilling was in progress and a detailed log prepared. A critical examination of this log shows that after entering the Permian the bore passed through coal seams at about 2,750 feet and 2,880 feet. Fragments of *Glossopteris* were found at 3,111 feet, 3,235-3,245 feet, and 3,290 feet. "Coaly particles" or "fragments of coal" (numerous at 3,615 feet) were recorded at 3,553 feet, 3,615 feet, and 3,695 feet. At 3,778 feet the first foraminifer was recorded (*Nodosaria* sp.) and Foraminifera were recorded at intervals thereafter to 4,465 feet. A short distance lower (4,495 feet) "indeterminate plant remains" were noted and "fragments of coal" were reported at close intervals from 4,520 feet to 4,667 feet. At 4,790 feet Foraminifera were again recorded and these with Ostracoda were present at fairly close intervals to the bottom of the bore, which was discontinued in a hard rock at 6,293 feet. This bottom rock is pebbly and contains shelly fossils.

In considering this record it is to be noted that coal is not recorded with the Foraminifera and that the reverse is also true; hence, we must conclude that the drillings are not unduly contaminated by cavings.

At a later date samples which had been put aside at the drill site were selected for examination by H. F. Whitworth of the Geological Survey of

<sup>1</sup> Department of the Interior.

New South Wales. These samples were panned and the concentrate examined for coal particles. Quite independently Mr. Whitworth found the coal fragments to be restricted to the intervals here noted.

The simplest and most reasonable explanation of these facts is that the normal Hunter River alternation of marine and fresh-water beds was proved in the Kulnura bore, the monotonous lithology commonly seen in out-crop being accentuated by off-shore conditions.

A large number of samples collected by various workers from exposures of Permian rocks in the lower Hunter Valley has been examined for their foraminiferal content by one of us (I.C.). This work has shown that a large number of forms ranges throughout most of the Permian sequence in the Hunter Valley. Three genera, however, *Frondicularia*, *Nodosaria*, and *Geinitzina*, have not been found higher than about the middle of the Branxton beds. One of these, *Nodosaria*, was the first foraminifer to be noted in the Kulnura cuttings.

Hence, knowing that considerable overlaps occur on the Kulnura-Lochinvar axis near Congewai (11 miles north of Kulnura), it seems very probable that the higher Marine Permian beds, including the Muree, were not proved in the bore, but that it passed directly from the upper Coal Measures into the Branxton beds, and when drilling ceased was about 1,600 feet into the lower Marine series.

On the foregoing criteria the following interpretation of the Kulnura log is suggested.

Unit	Depths in Feet	Thickness in Feet	Criteria
Upper Coal Measures	2,700-3,775	1,075	Coal seams and <i>Glossop- teris</i>
Upper Marine series (prob- ably Branxton stage)	3,775-4,490	715	Branxton type Foramini- fera
Lower Coal Measures	4,490-4,667	177	Plant remains and coal fragments
Lower Marine series	4,667-6,293	1,626+	Foraminifera

## REVIEWS AND NEW PUBLICATIONS

\* Subjects indicated by asterisk are in the Association library and available, for loan, to members and associates.

### O. C. MARSH, PIONEER IN PALEONTOLOGY, BY CHARLES SCHUCHERT AND CLARA M. LEVENE

REVIEW BY W. H. TWENHOFEL<sup>1</sup>

Madison, Wisconsin

*O. C. Marsh, Pioneer in Paleontology*, by Charles Schuchert and Clara M. LeVene. Published on the Foundation Established in Memory of Philip Hamilton McMillan of the Class of 1894, Yale College. Yale University Press, New Haven, Connecticut (1940). 541 pp., 30 pls., 33 text figs. Price, \$5.00.

This new biography of one of the American pioneers in vertebrate paleontology should be read by every student of science. It is, among other things, an analysis of the characteristics and attributes of one of the greatest scientists of the United States. It presents Marsh, the man, with his good and bad qualities; it presents the explorer, the collector, the biologist, the vertebrate paleontologist, and the stratigrapher. The book interestingly leads the reader from Marsh, the boy on a New York farm, to Marsh, president of the National Academy of Science; to the internationally famed vertebrate paleontologist and to the unsalaried professor of paleontology in Yale. In fifteen chapters, the reader is made acquainted with the ancestry of Marsh, his boyhood and his career in Andover and Yale. The reader travels with him in his early trip to Europe, goes with him on his expeditions to hunt fossils in the west, and sympathizes with him in his exposures of graft in the Government's Indian affairs. He learns to know Marsh's "bone diggers" and his laboratory assistants. He becomes acquainted with Marsh's uncle, George Peabody, the famed London banker, and with John Bell Hatcher, his great collector of vertebrate fossils.

Marsh's contribution to the theory of evolution and his part in the organization of the United States Geological Survey are given in interesting detail, and three chapters treat of Marsh's work on dinosaurs, toothed birds, mososaurs, flying reptiles, and fossil mammals. One chapter is devoted to Marsh as an individual and another to his home in New Haven, Connecticut, and the many interesting things that filled the home. Some aspects of the Marsh-Cope controversy are given, but it is obvious that the authors desire to treat this deplorable conflict with charity and to be silent respecting the disgraceful events that characterized much of it. The book contains a complete list of all articles and books published by Marsh.

The reviewer has been fond of biography since boyhood. Many biographies have been found interesting, others dull. Some did not carry impres-

<sup>1</sup> Department of geology, University of Wisconsin. Manuscript received, July 25, 1940.

sions of authenticity. The biography of Marsh holds the reader's interest from the first to the last sentence and leaves no doubt of its accuracy. The reviewer did not know Marsh and has not been interested in his field. The biography brought acquaintance and an appreciation of his contributions to science. Professor Schuchert and Miss LeVene are to be congratulated for having done an extremely excellent piece of work.

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OIL AND GAS FIELD DEVELOPMENT IN UNITED STATES, 1939,  
BY NATIONAL OIL SCOUTS AND LANDMEN'S ASSOCIATION

REVIEW BY G. S. DILLÉ<sup>1</sup>

Tulsa, Oklahoma

*Oil and Gas Field Development in United States, 1939*, by National Oil Scouts and Landmen's Association. Yearbook 1940. Review of 1939. Edited by Hervey L. Eversberg. 611 pp., maps, tables. Cloth. 8×10.75 inches. Published by the National Oil Scouts and Landmen's Association, Austin, Texas. Price, \$7.50.

This amazing and very informative volume is the tenth annual yearbook published by the National Oil Scouts and Landmen's Association, and is the first to present a complete review of development in all oil- and gas-producing states in the United States.

This volume, containing 605 pages, is a review of all drilling activity in the United States, all new fields discovered, their depth and producing formation, all completions, dry or as producers, all wildcat drilling, and all pertinent facts connected with each state and its 1939 experience.

Leasing information in both producing and non-producing states, geophysical exploration in each state, and maps showing new development and pipeline facilities are included. A discussion of well spacing and unitization in various pools is also included under the states where it is of present interest.

It is impossible to appreciate the mass of statistical information assembled in this publication without spending hours examining it. The volume includes statistics and graphs covering the nation's reserves and production by states. It also includes recovery per acre from every field in the United States and estimates of reserves for each pool. The figures covering Oklahoma and Kansas recovery per acre have been carefully checked against those compiled by major companies over long periods and in every instance have been found accurate.

All information that passed over the desk of either a scout or a landman during 1939 seems to have been incorporated within this book. It is without doubt one of the greatest volumes of oil and gas statistical information ever assembled. It is one of the most important reference books in the industry. No company, engineer, or geologist should be without it.

The National Oil Scouts and Landmen's Association is to be highly commended for their immense effort and its successful completion.

<sup>1</sup> Consulting geologist, 808 Atlas Building. Manuscript received, August 2, 1940.

GEOLOGY OF THE SUB-ANDEAN BELT OF BOLIVIA, BY  
GLYCON DE PAIVA, JORGE MUÑOZ REYES,  
AND GUILLERMO MARIACA

REVIEW BY JOHN L. RICH<sup>1</sup>  
Cincinnati, Ohio

"Geologia da Faixa Subandina da Bolivia" (Geology of the Sub-Andean Belt of Bolivia), by Glycon de Paiva, Jorge Muñoz Reyes, and Guillermo Mariaca. *Boletín 101, Ministério da Agricultura, Departamento Nacional da Produção Mineral, Divisão de Geologia e Mineralogia* (Rio de Janeiro, 1939). 83 pp. with aerial photographs and sketch geological map in color.

The sub-Andean belt of Bolivia is a strip about 30 miles wide immediately east of the high Andes.

An agreement between Bolivia and Brazil aiming at the utilization of Bolivian oil and its passage through Brazilian territory led to a field reconnaissance of the potentially petroliferous sub-Andean belt and a review of all available literature through 1937 by a group of two Bolivian and one Brazilian geologists. The results, published in Portuguese, comprise the bulletin under review.

In the introduction the authors emphasize the present inadequate understanding of the geology of the region, particularly of its stratigraphy, which they attribute to inaccessible and difficult terrain, inadequate maps, and especially to a difficult stratigraphic section containing a great thickness of mainly continental beds of similar lithology ranging in age from early Paleozoic to upper Tertiary and very poor in fossiliferous key beds suitable for correlation.

The chapter on stratigraphy presents and discusses in considerable detail the stratigraphic sections worked out by d'Orbigny, Bonarelli, Heald and Mather, Mather, Schlagintweit, the Argentinian Y.P.F., and Frenguelli, and an attempt is made to harmonize these graphically in a chart entitled "Tentative Correlation of Sections." Another chart prepared by Cañedo Reyes shows the "Position of the Petroliferous Horizons in the Sedimentary Column of the Sub-Andean Belt."

Physiography and tectonics are treated in separate chapters, but since the physiography closely reflects the tectonics, the two are here reviewed together. A physiographic map of Bolivia subdivides the country into the "Puna," the high arid inter-Andean basin extending southward from Lake Titicaca into Argentina; the "Sub-Puna," between the Cordillera Real, the high range on the east border of the Puna and the first of the sub-Andean folded chains—essentially the eroded eastern side of the Andean plateau; the "Faixa Sub-Andina" (sub-Andean belt); the "Piemonte Andino" (Andean Piedmont); and the great eastern plain called the "Planicie Beniama Amazonica" at the north and "El Chaco" at the south.

The sub-Andean belt is marked by long ridges and intervening lowlands. The ridges are either stripped anticlines of resistant rock—generally Paleozoic—or are the outcrops of the resistant beds on the flanks of anticlines that have been breached at the top. The lowlands are generally synclinal and

<sup>1</sup> Department of geology, University of Cincinnati. Manuscript received, August 5, 1940.

underlain by Mesozoic rocks. Simple long folds are the commonest structures, but some are broken by thrust faults with displacements up to 2 or 3 miles. Thrusting and overturning are from the west.

The Andean Piedmont belt is a strip of land of intermediate elevation between the easternmost of the longitudinal folds and the flat plains of the Chaco.

Some of the rocks underlying the folds are bituminous and numerous seepages occur along the anticlines and faults. Oil has been found in shallow wells at several places. A rather extensive program of exploration and test drilling is recommended.

The bulletin with its bibliography and discussion of the literature should prove a useful foundation for the necessary further work in the region.

## RECENT PUBLICATIONS

### CALIFORNIA

\*"California Reserves Maintained by Intensive Exploration," by Roy M. Barnes. *Oil and Gas Jour.* (Tulsa), Vol. 39, No. 9 (July 11, 1940), pp. 40-41, 101-03; 3 curve charts.

### GENERAL

*A Catalogue of Foraminifera*, by Brooks F. Ellis and Angelina R. Messina. 30 vols., 30,000 pp., est., text and illustrations. 8.5×11 inches. Loose-leaf, ledger-type post binder. First volume ready about August, entire work to be completed by end of 1940. Each genus and species treated as separate unit. Generic units contain type reference, transcript of original description, type species where designated by author, and chronologically arranged list of subsequent reference. Species units include type reference, type figure, transcript of original description, type level and locality, depository of types, and chronologically arranged list of subsequent references. Publication of the catalogue is part of a program of service offered by the American Museum of Natural History in establishing a department of micropaleontology. Benefits of the program are available through membership in the department. Initial membership open to all interested, \$100 (includes 30,000-page catalogue). For continuing and active memberships and other details, write Department of Micropaleontology, American Museum of Natural History, Central Park West at 79th Street, New York City.

"Geophysical Abstracts 96, January-March, 1939," compiled by W. Ayvazoglou. *U. S. Geol. Survey Bull.* 915-A (1940). 48 pp. For sale by Supt. of Documents, Govt. Printing Office, Washington, D. C. Price, \$0.10.

*The Rhythm of the Ages (Earth History in the Light of the Pulsation and Polar Control Theories)*, by Amadeus W. Grabau. 561 pp., 126 figs., 25 pls. and maps, 32 tables. Cloth-bound. Outside dimensions, approx. 7×10.25×2 inches. The French Bookstore, Henri Vetch, Peking (Peiping), China (1940). Price: China, \$30 Mex., £1; U. S., \$5.00.

\**Petroleum Development and Technology, 1940*, by the Petroleum Division. *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 136. 608 pp., illus. Published by the Institute, 29 West 39th Street, New York City. Cloth. 6×9 inches. Price, \$5.00 net.

\*"Progress in Squeeze Cementing Application and Technique," by Paul D. Torrey. *Oil Weekly* (Houston), Vol. 98, No. 8 (July 29, 1940), pp. 68-84; 3 tables.

\*"Technical Advances and Economics of Water Floods," by L. M. Arnold and R. C. Earlougher. *Ibid.*, pp. 105-10; 3 figs.

#### GREAT BRITAIN

\*"The Geology of an Area of Salopian Rocks West of the Conway Valley, in the Neighbourhood of Llanrwst, Denbigshire," by P. G. H. Boswell and I. S. Double. *Proc. Geologists' Assoc.* (London), Vol. 51, Pt. 2 (June 28, 1940), pp. 151-87; 2 figs., 1 folded map in colors.

\*"The Salopian Rocks of the Clwydian Range between the Bodfari Gap and Moel Llys-y-coed, Flintshire," by Brian Simpson. *Ibid.*, pp. 188-206; 4 figs., 2 photographs, 1 folded geological map.

#### IRAN AND IRAQ

\*"The Geology of the Oil-field Belt of S. W. Iran and Iraq," by G. M. Lees and F. D. S. Richardson. *Geological Magazine*, Vol. 77, No. 3 (May-June, 1940), pp. 227-52; 2 figs. Stephen Austin and Sons, Ltd., 1 Fore Street, Hartford, Herts, England.

#### LOUISIANA

\**Louisiana Dept. Conservation 14th Bien. Rept., 1938-1939*, published by Dept. of Conservation, 126 Civil Courts Building, New Orleans (1940). 416 pp., illus. and 39 sheets in pocket, including oil and gas statistics by fields, oil and gas production by parishes, map of oil and gas fields. Work and publications of State Geological Survey described on pp. 211-61, including tentative stratigraphic column. 6×9 inches. Paper cover.

#### MICHIGAN

\*"Walker Field, Kent and Ottawa Counties, Michigan," compiled by *Oil and Gas Journal Service on Active Fields. Oil and Gas Jour.*, Vol. 39, No. 12 (August 1, 1940), pp. 25-27; 1 map.

#### NORTH DAKOTA

\*"Careful Exploration Required in North Dakota Oil Search," by Frank C. Foley. *Oil and Gas Jour.* (Tulsa), Vol. 39, No. 10 (July 18, 1940), pp. 14-15; 1 geologic map.

#### PENNSYLVANIA

"Some Structural Features of the Northern Anthracite Coal Basin, Pennsylvania," by N. H. Darton, *U. S. Geol. Survey Prof. Paper 193-D* (1940), pp. 69-81, Pls. 10-19, Figs. 7-19. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, \$0.50.

#### RUSSIA

*Atlas of the Leading Forms of the Fossil Faunas of the U.S.S.R.: Vol. V, The Middle and Upper Carboniferous*, by I. Gorsky, V. Weber, L. Librovitch, B. Licharew, A. Nikiforova, V. Ruzencev, A. Fraas, V. Fomitchev, B. Tschernychew, A. Khabakov, and N. Yakovlew. 179 pp., 37 figs., 35 pls. Abstract by Carl O. Dunbar in *Amer. Jour. Sci.*, Vol. 238, No. 8 (New Haven,

Connecticut, August, 1940), p. 607. Central Geological and Prospecting Institute, Leningrad (1939).

*Atlas of the Leading Forms of the Fossil Fauna of the U.S.S.R.*: Vol. VI, *Permian*, by B. Licharew, E. Lutkevich, A. Martynov, A. Riabinin, E. Soshkina, T. Spizharsky, A. Khabakov, A. Tschernov, B. Tschernyschew, M. Shulga-Nesterenko, and N. Yakovlew. 268 pp., 113 figs., 56 pls. *Ibid.*

\*"Problems of Oil-Bearing Paleocene and Miocene Strata of Kabristan," by B. V. Weber. *Trans. Geol. Oil Inst.*, Ser. A, Fascicle 110 (Moscow, 1939). 112 pp., 5 figs., geological tectonic folded map in colors. In Russian.

\*"Geology of the Region from the Samur River to the Main Range of the Caucasus and the Schach-Dagh Zone," by D. W. Drobyschew. *Ibid.*, Fas. 111. 44 pp., 5 figs., correlation table. Pp. 41-43, abstract in German.

\*"Lithology of Oil-Bearing Carbonate Rocks of Middle Asia and Genesis of Oil-Bearing Dolomite," by V. B. Tatarsky. *Ibid.*, Fas. 112. 90 pp., 3 figs., 6 pls. of photomicrographs. Pp. 86-87, summary in English.

\*"Mollusks of the Lower Oligocene of the Northern Caucasus," by I. Korobkov. *Ibid.*, Heft 113, 94 pp., 39 figs., 9 pls. of fossils, Pp. 80-87, abstract in German.

\*"Stratigraphy of Upper Jurassic Deposits of the Ural-Emba Region," by E. I. Sokolova. *Ibid.*, Fas. 114. 46 pp., map, correlation table.

\*"Materials on Stratigraphy and Oil Occurrence in the Southern Urals," by E. Alexandrova, E. Glebovskaia, M. Kulikov, B. Nalivkin, G. Dmitriev, A. Nikiforova, N. Palitsin, O. Radchenko, V. Sermjaghin, D. Stepanov, and V. Trizna. *Ibid.*, Fas. 115. 254 pp. 10 articles with English summaries. Pls., figs., tables.

\*"Articles on Microfauna," by B. Keller, N. Subbotina, N. Voloshinova, and A. Schweyer. *Ibid.*, Fas. 116, 103 pp. 4 articles with English summaries. Pls., tables.

\*"The Maikop Deposits of the Kerch Peninsula," by Z. Majmin. *Ibid.*, Fas. 117. 35 pp., 3 figs. Abstract in English.

\*"Stratigraphy of Variegated Series and Jurassic Deposits in the Emba District," by N. A. Khramov. *Ibid.*, Fas. 118. 68 pp., 8 figs., tables.

\*"Geological Investigations in the Southwestern Part of North Sakhalin," by E. Smekhov. *Ibid.*, Fas. 119. 19 pp., 3 figs.

\*"Foraminifera from Upper Jurassic and Lower Cretaceous Deposits of the Middle Volga Region and Obschiy Syrt," by E. Mjatluk. *Ibid.*, Fas. 120. 76 pp., 2 figs., 4 pls. of fossils, distribution tables. Pp. 68-74, summary and species descriptions in English.

\*"Foraminifera from Upper Cretaceous and Paleogene Deposits of Ferghana," by N. Bykova. *Ibid.*, Fas. 121. 47 pp., 2 figs., 4 pls. of fossils. Pp. 33-37, summary and species descriptions in English.

\*"Geological Section across the Red Mound in the Middle Mountain Range of Kamchatka," by M. Dvali. *Ibid.*, Fas. 122. 28 pp., folded cross section.

\*"Tertiary Deposits in the Utholok District," by I. Pleshakov. *Ibid.*, Fas. 123. 38 pp., 8 figs.

\*"Gastropoda from Tertiary Deposits of the West Coast of Kamchatka," by A. Ilyina. *Ibid.*, Fas. 124. 90 pp., 15 pls. of fossils. Pp. 75-83, summary and fossil descriptions in English.

\*"Foraminifera Occurring in the Bays of the Ohotsk Sea," by N. Voloshinova and A. Petrov. *Ibid.*, Fas. 125. 23 pp. Abstract in English.

\*"Ostracoda of Upper Jura and Cretaceous of the Region of St. Ozinki (Middle Volga Area)," by E. Sharapova. *Ibid.*, Fas. 126. 51 pp., 4 pls. of fossils, distribution chart. Pp. 38-47, abstract and species descriptions in English.

\*"Stratigraphy of Mesozoic Series in the Region of Khaltan-Leguitch (Southeastern Caucasus)," by Z. Mishunina. *Ibid.*, Fas. 127. 40 pp., 3 figs.

\*"Fauna and Stratigraphy of Lower Cretaceous in Northwestern Caucasus," by N. Luppov. *Ibid.*, Fas. 128. 44 pp., 6 figs., 8 pls. of fossils. Pp. 39-41, summary and species descriptions in English.

\*"Stratigraphy of Paleogene in the Tadjik Depression," by O. Vialov. *Ibid.*, Fas. 129. 35 pp., 2 figs.

## TEXAS

\*"Rincon Field in South Texas Being Steadily Extended," by Neil Williams. *Oil and Gas Jour.* (Tulsa), Vol. 39, No. 12 (August 1, 1940), pp. 13-15; subsurface contour map, geologic cross section, photographs.

## ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

\**Journal of Sedimentary Petrology* (Tulsa, Okla.), Vol. 10, No. 2 (August, 1940).

"Textural and Shape Variation in the Berea Sandstone of Ohio," by Fred Foreman and Harry L. Thomsen

"Areal Variations of Calcium Carbonate and Heavy Minerals in Barataria Bay Sediments, Louisiana," by L. T. Caldwell

"Beach Sediments of Trout Lake, Wisconsin," by V. E. McKelvey

"Compaction of Lime Mud as a Cause of Secondary Structure," by Ruth D. Terzaghi

"Suggestions for the Facilitation of Grain Count with the Petrographic Microscope," by William A. White

"A New Centrifuge Tube for Heavy Mineral Separation," by W. E. Bertholf, Jr.

"Notes on Limit of Sediment Concentration," by E. W. Lane

## THE ASSOCIATION ROUND TABLE

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### MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

#### FOR ACTIVE MEMBERSHIP

Richard Pete Akkerman, Houston, Tex.

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TWENTY-SIXTH ANNUAL MEETING, HOUSTON  
APRIL 2-4, 1941

The twenty-sixth annual meeting of the Association will be held at the Rice Hotel, Houston, Texas, April 2, 3, and 4, 1941. The Houston Geological Society, at whose invitation the meeting is being held there, has already selected several of the convention committees to make preliminary arrangements. President WALLACE C. THOMPSON, of the Houston Society, announces that plans are already under way and that the remaining committee chairmen and committee members will be appointed after the election of new local society officers in October.

The general committee, or "steering committee," is headed by ALEXANDER DEUSSEN and consists of W. B. HEROY, L. P. GARRETT, JOHN M. VETTER, CLIFF BOLES, and ROY L. BECKELHYMER.

The hotel and registration committee is headed by OLIN G. BELL and consists of K. H. CRANDALL, J. A. WHEELER, W. A. GORMAN, and F. G. EVANS.

PERRY OLCOTT heads the program committee and will have several local assistants, who will be selected later. Regional chairmen will be appointed in Association districts.

Another committee, which is relatively new, is a committee from the Houston Society to prepare an exhibit of Gulf Coast geology to help visitors understand problems peculiar to the Gulf Coast. This exhibit committee is headed by PAUL WEAVER and consists of LON D. CARTWRIGHT, J. BRIAN

EBY, WALTER H. SPEARS, F. W. ROLSHAUSEN, W. F. CALOHAN, and W. E. GREENMAN.

J. A. CULBERTSON is chairman of the field trips committee.

Additional committee appointments and further details of the convention will be announced later.

In conjunction with the A.A.P.G. convention, the fifteenth annual meeting of the Society of Economic Paleontologists and Mineralogists and the eleventh annual meeting of the Society of Exploration Geophysicists will be held in the same hotel,—the Rice.

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WEST TEXAS GEOLOGICAL SOCIETY FALL MEETING  
AUGUST 17, 1940. ABSTRACTS

The fall meeting of the West Texas Geological Society had an attendance of 177 persons at the Scharbauer Hotel, Midland, August 17. Following the technical program a barbecue-smoker was enjoyed at Cloverdale Park. The officers of the Society are: president, JOHN EMERY ADAMS, Standard Oil Company of Texas; vice-president, DANA M. SECOR, Skelly Oil Company; and secretary-treasurer, FRED F. KOTYZA, Tide Water Associated Oil Company. Committee chairmen for the meeting were as follows: general chairman, TAYLOR COLE, University Lands; program, E. RUSSELL LLOYD, consultant; entertainment, W. E. DAUGHERTY, Humble Oil and Refining Company; arrangements, W. L. HASELTINE, Magnolia Petroleum Company; publicity, FRANK GARDNER, Midland *Reporter-Telegram*. Speakers, subjects, and abstracts of papers follow.

LEO HENDRICKS, geologist, Bureau of Economic Geology, University of Texas, Austin: A Study of the Surface Stratigraphy of the Ellenburger Formation of Texas (abstract).

The Ellenburger formation of Texas is a series of limestones and dolomites of Cambro-Ordovician age. A detailed study of the outcrops reveals that the formation may be divided into at least three cartographic units. Criteria for recognition of the units in the field are lithologic character and type of weathered cherts. Faunal correlation of the units can be indicated.

ROSCOE SIMPSON, geologist, Cardinal Oil Company, San Angelo: The Page Field in Schleicher County, Texas (abstract).

The Page field is in the physiographic province known as the Edwards Plateau. Despite the wide spacing of the wells drilled, the field is as yet undefined, especially to the north.

In regard to Permian stratigraphy, sections made up predominantly of shale and sandstones occur over structural basins, and those which are predominantly limestone occur over structurally high platforms. The Permian section of Schleicher County grades laterally into gray and black shales in the southwestern part of the county and consists of limestone in the north-eastern part of the county.

On top of the Strawn limestone, a rather pronounced structural feature is evident with 400 feet of dip between two of the wells. The distance to the top of the gas zone or porous zone as measured from top of Strawn limestone is variable, ranging from 50 feet of penetration in one well to 170 feet in another well.

From the insoluble-residue work done to date, there seems to be a good marker of chalky chert with siltstones disappearing about 15 feet in the porous zone.

RONALD K. DEFORD, geologist, Argo Oil Corporation, Midland: Insoluble Residues in the Whitehorse and Salado of New Mexico.

The author discussed briefly results obtained by Neil H. Wills and others by means of insoluble residues of well cuttings from the Salado salt and the upper Whitehorse dolomite. He also criticized hurried sample examination and the discarding of salt and redbed samples as unimportant.

R. L. CANNON, geologist, Cannon and Cannon, San Angelo: Section Encountered in the Krupp Wells, Hudspeth County, Texas (abstract).

The two wells being drilled by Haymon Krupp Oil and Land Company in Hudspeth County are the Briggs No. 1, located in the northeast quarter of Sec. 24, Block 73, Township 7, T & P Ry. Co. Survey, and the Thaxton No. 1, located in Sec. 34, Block 74, Township 6, T & P Ry. Co. Survey. The Briggs is now drilling below 6,206 feet. It is a projected Ordovician test. The Thaxton is temporarily shut down at a total depth of 6,402 feet.

The surface structure of the area is accounted for by thrust folding and faulting. The Malone Mountains, adjacent to which the Briggs is now drilling, clearly exhibit this structure.

The Briggs well encountered Permian rocks overthrust and resting on Upper Cretaceous shales underneath which there is a normal sequence, including a full section of Comanche (Lower Cretaceous) and Permian strata.

The Thaxton penetrated the Campagrande formation (lower Comanche) overthrust on the Buda formation. Below the fault plane there is a normal sequence including from top down, Comanche, some possible Jurassic and Permian strata.

CARY P. BUTCHER, geologist, Tide Water Associated Oil Company, Midland: Photographs of the Sacramento Mountains.

A series of slides.

FRANK E. LEWIS, consulting geologist, Midland: Position of the San Andres Group, West Texas and New Mexico (abstract).

Stereograms were made of a wide area of the South Permian basin to gain a regional perspective of the upper Permian stratigraphy. Recognized as major structural features are the Val Verde basin, Fort Lancaster platform, Blackstone arch, Cerf basin, San Simon syncline, and Halfway syncline. Structural features were controlling factors in Permian deposition and the stratigraphic phenomena of the Permian basin are related directly to lateral gradation. Surface studies and subsurface work reveal that as a result of this gradation many of the various facies are time equivalents. Unconformities are recognized as the best time markers because of the changing facies. Surface trace reveals that several hundred of Word clastics grade into the Vidrio limestone in the northeastern Glass Mountains. Consequently, the Vidrio is recognized as the upper division of the Word and the Capitan formation is restricted to the reef facies of the Gilliam to conform with its usage in the Guadalupe Mountains. It is proposed to place the base of the Word at a conglomerate about 300 feet below the present base of the formation.

In the Glass Mountains, evidence suggests the Whitehorse unconformity at the base of the Gilliam, and the unconformity at the base of the Word is believed to be equivalent to the unconformity at the base of the El Renos.

The San Andres group is believed by Lewis to be the time equivalent of the Word formation, the lower two divisions of the Delaware Mountain group, and the El Reno group, each of which is separable into upper and lower divisions over a wide area in the South Permian basin. These correlations were later supplemented by paleontologic information which shows that a preponderance of evidence is accumulating that the San Andres group should be placed in the Guadalupe series instead of the Leonard series.

R. T. COX and N. B. WINTER, geologists, Atlantic Refining Company, Midland: Whitehorse-San Andres Contact on and adjacent to Central Basin Platform (abstract).

Two types of dolomitic limestones are recognized between the basal Grayburg sand and the Glorieta member, each representing a different type of depositional environment and separated by an unconformity. The upper beds are of Whitehorse age and the lower beds are equivalent to the San Andres formation of southeastern New Mexico. The Goldsmith formation was defined in this paper and illustrated by cross sections.

TAYLOR COLE, geologist, University Lands, Midland, and C. M. LINEHAN, geologist, Standard Oil Company of Texas, Midland: Insoluble-Residue Study of the Holt "Pay," Ector County, Texas (abstract).

The Holt "pay" was discovered in the Gulf Oil Corporation's O. B. Holt No. 1 in July, 1939, and is 950 feet below the regular North Cowden pay zone. There has been some controversy as to the age of the Holt "pay." Opinions have varied from Whitehorse to Clear Fork. It is the writers' opinion that the "pay" is middle San Andres in age and is stratigraphically 200 feet below the McKnight "pay" of Crane County and 600 feet above the Tubb "pay" of Crane County.

An interesting comparison is made of various San Andres tops from different companies and their relation with zones below the top of the San Andres are shown. It is the writers' opinion that top of the San Andres is lower than most workers are picking. Three mappable chert zones are found in the San Andres with no appreciable chert occurring above this formation.

JOHN A. BARNETT, district engineer, United States Geological Survey, Roswell, New Mexico: Producing Zones of Eddy County, New Mexico (by title).

W. T. SCHNEIDER, geologist, Honolulu Oil Corporation, Midland: Wasson Pool, Gaines and Yoakum Counties, Texas (by title).

## AT HOME AND ABROAD

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### CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

Seventeen members of the Northeastern Ohio Geological Society took a five-day excursion through Pennsylvania and New York states over the weekend from July 19 to July 23. Two cross sections of the Appalachians were traversed; the anthracite coal fields were visited, as well as typical sections in New York state where many Paleozoic formations were originally named and described. Of great interest to the petroleum geologists were the first gas seepage reported in the New World at Burning Springs, near Bristol Center, the original Seneca Oil Spring near Cuba, New York, and the original oil well of Colonel Drake at Titusville, Pennsylvania. The members of the party wish to express their gratitude to GEORGE H. ASHLEY and RICHARD M. FOOSE, of the Pennsylvania Geological Survey, and C. A. HARTNAGEL, of the New York Survey, for working out the details of the excursion and for their kind assistance in conducting them through their respective states. LINN M. FARISH, of the Magnolia Petroleum Company, Youngstown, Ohio, is president of the Northeastern Ohio Geological Society.

Continued studies in Silurian problems in southeast Missouri have been made possible for JOHN R. BALL, of the department of geology, Northwestern University, Evanston, Illinois, by an expense fund provided by H. A. BUEHLER, State geologist of Missouri. Later Ball is planning to examine some of the Silurian in states west of the Rocky Mountains.

IRA H. CRAM has been appointed assistant to the chief geologist, THERON WASSON, of the Pure Oil Company at Chicago, Illinois. Effective September 1, his home address will be 560 Sheridan Road, Winnetka, Illinois. Cram has been with the company 16 years. He is succeeded as division geologist in the southwestern division at Tulsa, Oklahoma, by MYRON C. KRESS.

GAIL F. MOULTON, for many years on the staff of Ralph E. Davis, Inc., Pittsburgh and New York, has resigned and is engaged in independent consulting work. His home is at Mountain Lakes, New Jersey.

H. G. RAGGATT has resigned from the Geological Survey of New South Wales to take up the position of assistant geological adviser to the Commonwealth Government of Australia. He is stationed at Canberra.

NELSON J. RUMSEY, JR., geologist with Core Laboratories, Inc., is occupied with core analysis work in the North Texas area, having been transferred from Houston to 1716 Eleventh Street, Wichita Falls, Texas.

ARTHUR J. TIEJE, professor of geology at the University of Southern California, Los Angeles, has returned from Tahiti with Foraminifera collected from the coast there. This is of interest to others working with Foraminifera, because of the lack of publications on collections from that area.

CARL B. IRWIN, recently with the Lago Petroleum Corporation at Maracaibo, Venezuela, may be addressed at 1819 Crockett Street, El Paso, Texas.

LEWIS B. KELLUM has changed his address from the New Zealand Petroleum Company Ltd., Gisborne, New Zealand, to the Museum of Paleontology, Ann Arbor, Michigan.

H. D. HOBSON, formerly with the Continental Oil Company, is with the General Petroleum Corporation, Bakersfield, California.

ELMER W. ELLSWORTH, executive secretary of the Independent Producers Association of Illinois, is available for independent consulting work in geology and geophysics. His office is in the Wham Building, 212 East Broadway, Centralia, Illinois.

R. P. McLAUGHLIN has resigned as general manager of the Dominguey Oil Fields Company and will engage in consulting work with offices at 850 Subway Terminal Building, Los Angeles, California.

FLOYD A. NELSON, of the geological department of the Shell Oil Company, Inc., at St. Louis, Missouri, has been transferred to the exploration department of the company at Houston, Texas.

WALTER H. MADDOX has left New Guinea and may be addressed as follows: Caltex (Australia) Oil Development Proprietary Limited, Box 1593-BB, G. P. O., Sydney, New South Wales, Australia.

KNIGHT KEITH SPOONER, district geologist for the Atlantic Refining Company, has moved from Houston, Texas, to Jackson, Mississippi.

H. J. MCCREADY is party chief of a Mott-Smith gravimeter crew. He may be addressed in care of T. F. Roche, Apartado Aero 32, Barranquilla, Colombia, S. A.

G. E. ANDERSON, professor of geology at the University of Oklahoma, at Norman, died on August 31 at the age of 61 years.

A. H. GARNER, geologist and engineer, announces the removal of his office to the Continental Building, Dallas, Texas, on September 1.

W. F. CHISHOLM, director of the Division of Research and Statistics of Louisiana Department of Conservation, New Orleans, has an article, "The Man with the Hoe," in the Spring, 1940, issue of the *Louisiana Conservation Review*, in behalf of wild life conservation.

JOHN JAY JAKOSKY, president of International Geophysics, Inc., of Los Angeles, California, has been appointed dean of the School of Engineering of the University of Kansas. He is the author of a new book, *Exploration Geophysics*.

C. WINTHROP PAYNE, student computer on a seismograph crew for the Carter Oil Company, recently moved from Warren, Ohio, to Ardmore, Oklahoma.

JERRY R. KYLE, of the Carter Oil Company, has moved from Mattoon, Illinois, to Tulsa, Oklahoma.

THEODORE G. GLASS, is geologist for the Exchange Oil Company, a subsidiary of the Sinclair Prairie Oil Company, at Evansville, Indiana.

WARREN H. WYNN, recently at Shawnee, Oklahoma, is district geologist for the Sinclair Prairie Oil Company in Ohio and western Pennsylvania.

LOUIE C. KIRBY, recently paleontologist and petrographer with The Texas Petroleum Company at Bogota, Colombia, may be addressed at Box 523, Heber Springs, Arkansas.

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GEOLOGICAL SOCIETY OF AMERICA  
AUSTIN, TEXAS, DECEMBER 26-28, 1940

The Geological Society of America will hold its fifty-third annual meeting at The University of Texas, Austin. The Society, through the office of the secretary, C. P. Berkey, has extended an invitation to all members of The American Association of Petroleum Geologists to attend this meeting. Dr. Berkey says in his letter of August 5 to the secretary-treasurer of the Association, Edgar W. Owen:

As you may know, The Geological Society of America will holds its 53d Annual Meeting at Austin, Texas, December 26-28, 1940, under the auspices of The University of Texas. The Paleontological Society and the Mineralogical Society of America will hold meetings in conjunction with the Annual Meeting of the Geological Society.

We recall that in 1931 The American Association of Petroleum Geologists held joint meetings with The Geological Society of America in Tulsa, and that in connection with our 1933 meeting, at Chicago, and the 1939 meeting, at Minneapolis, special invitation was given to members of the Association to join with us. This year, when we are holding meetings in Austin, we believe that there is a signal opportunity to strengthen the bond of friendship and mutual interests that ties your organization to our own; and we would like to extend a cordial invitation to The American Association of Petroleum Geologists, its sections, divisions, and affiliates, with their individual members, to attend our meeting and take part in its functions. We hope that you and the other officers of the Association, together with many of your members, will attend; and if it should be practicable for the Association to organize a special program of scientific papers we will be glad to make arrangements therefor.

If individual members of the Association wish to submit titles for the program, abstract blanks will be forwarded on request and their offerings will be considered by our Program Committee in the usual manner.

The local committee at Austin is making arrangements for a large meeting and assure the members that the accommodations available will be sufficient for all who wish to come. The meetings will be held in the Union Building of The University of Texas which is admirably adapted to this purpose. The meeting is held on December 26, 27, 28. Excursions are being planned into the pre-Cambrian, Paleozoic, Cretaceous, and Tertiary formations within easy travel distance of Austin.

In order that the several committees engaged with problems of preparation may know how many A.A.P.G. members plan to attend, and in order that those planning to attend may be placed upon G.S.A. mailing lists to receive preliminary announcements and programs, arrangements have been made with secretary E. W. Owen to receive word of their intentions from members of the Association and to relay them to the G.S.A. at its headquarters in New York.

## FIELD TRIPS

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### WEST TEXAS GEOLOGICAL SOCIETY, SEPTEMBER 28-29

The fall field trip of the West Texas Geological Society will take place in Eddy County, New Mexico, on the last week end in September. It will assemble at the La Caverna Hotel in Carlsbad, Friday night, September 27, 1940.

The theme of the trip is the relation of subsurface formations to surface formations. On the first day, Saturday the 28th, the leaders will attempt to demonstrate the relations between the Yates and Tansill formations and the Capitan, Castile, and Salado. On the second day, Sunday, September the 29th, the "Red sand" key-bed at the top of the Queen formation will be studied in both subsurface and surface; and the San Andres problem will be brought up.

The road log will contain 30 pages, 2 figures, and a road map. The areal geology shown on the road map and numerous measured sections in the log have not been published elsewhere.

The leaders will be Ronald K. DeFord, Neil H. Wills, and George D. Riggs.

All reservations should be made through Georges Vorbe, Midland, Texas. To insure receiving the accommodations you wish, please make your reservation now as a large attendance is expected. Road logs may be purchased in advance of the trip. The price of \$1.50 includes registration.

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### APPALACHIAN GEOLOGICAL SOCIETY, OCTOBER 4-5

The Appalachian Geological Society will sponsor a field trip to be held in the Niagara Gorge area on Friday and Saturday, October 4 and 5.

C. A. Hartnagel, assistant State geologist of New York, will be in charge. The purpose of the trip is an outcrop study of formations with deep producing possibilities in the Appalachian area.

L. C. Snider, president of the A.A.P.G., will address a dinner meeting on the evening of October 4 and R. E. Sherrill, of the University of Pittsburgh, will talk on "Stratigraphic Traps in the Appalachian Fields."

Following the two-day field trip, a number of short trips will be arranged through producing fields for those interested in Oriskany gas or secondary recovery of oil. Geologists interested in this trip are requested to send their names immediately to the president of the Appalachian Geological Society, J. R. Lockett, Ohio Fuel Gas Company, Box 117, Columbus, Ohio, who will place the names on a mailing list for the itinerary and other details. An indication of the number of persons interested is necessary to make arrangements.

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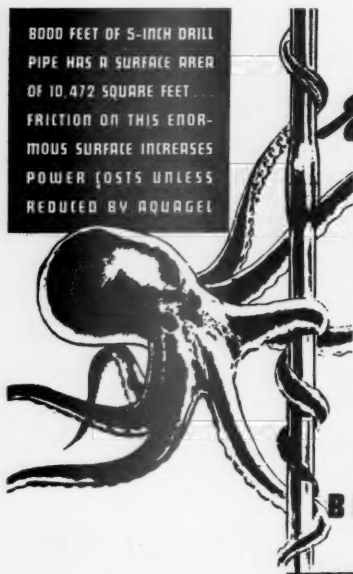
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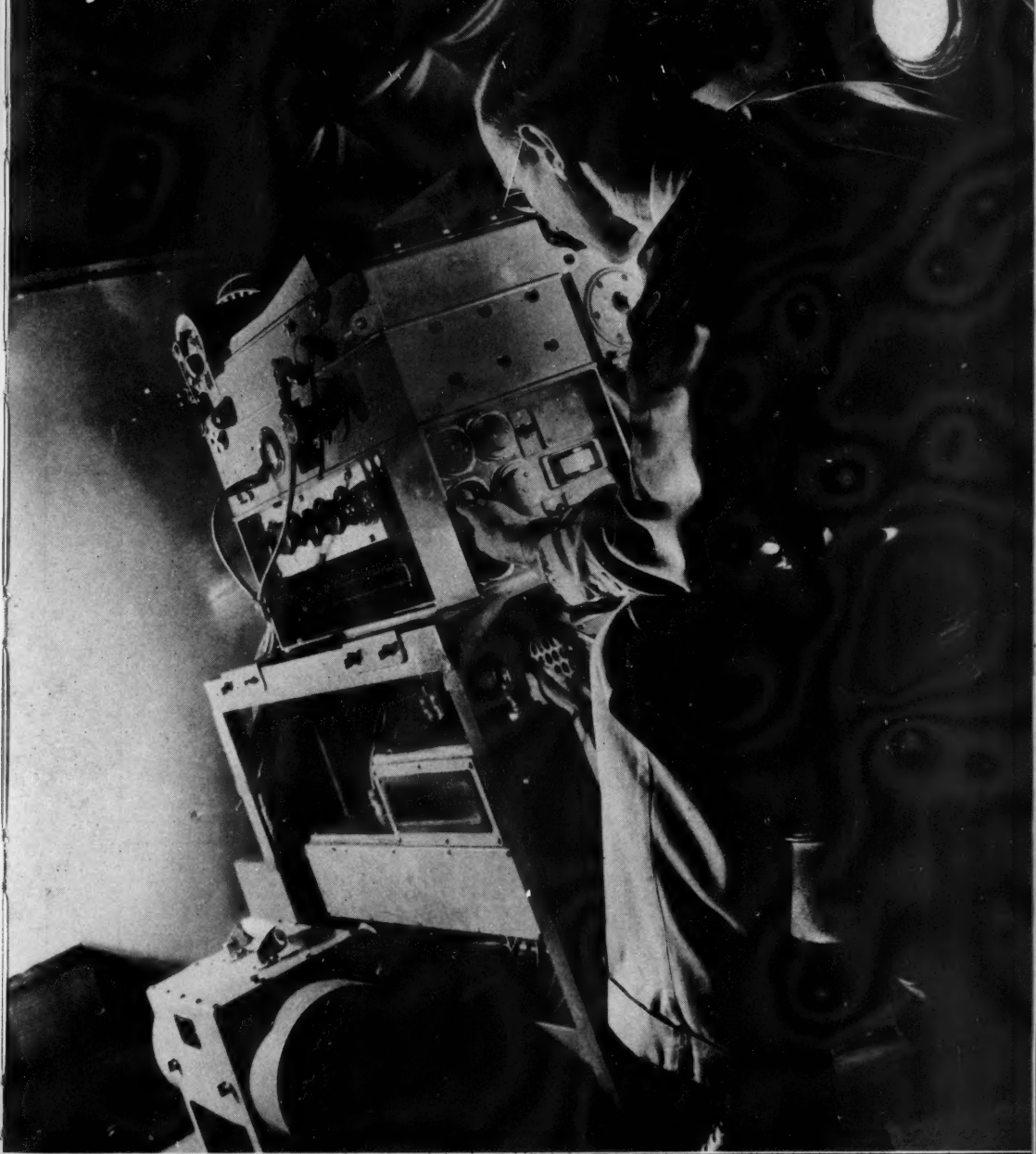
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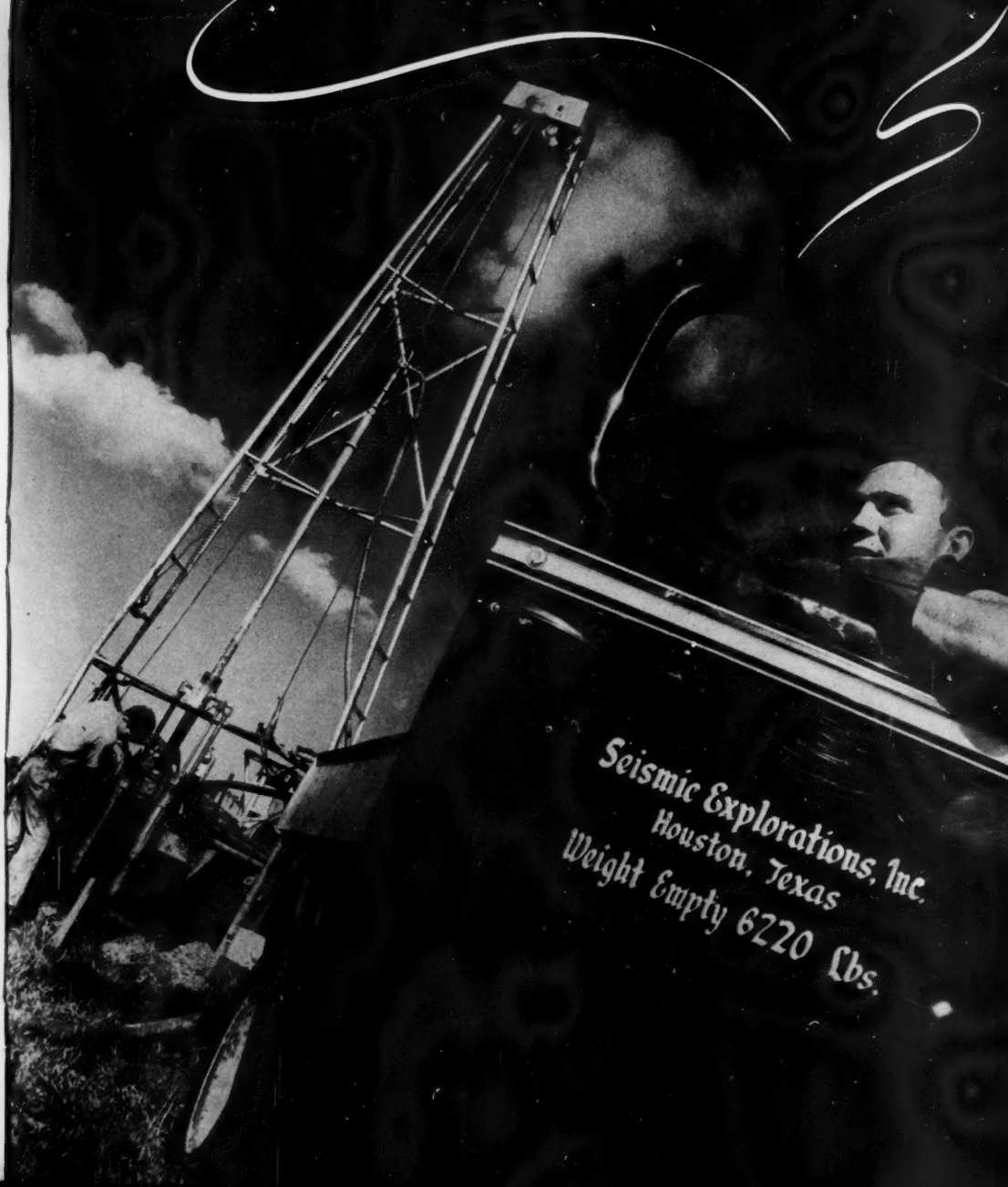
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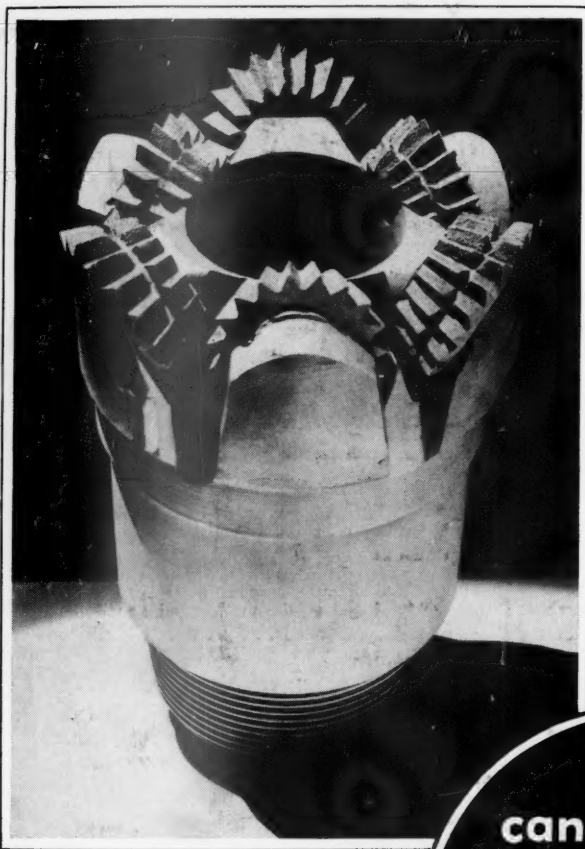
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